JOURNAL

OF THE

FRANKLIN INSTITUTE

OF THE STATE OF PENNSYLVANIA,

FOR THE PROMOTION OF THE MECHANIC ARTS.

VOL. CLVI, NO. 3. 78TH YEAR. SEPTEMBER, 1903

THE Franklin Institute is not responsible for the statements and opinions advanced by contributors to the *Journal.*

ELECTRICAL SECTION.

Stated Meeting, held Thursday, January 8, 1903.

Automatic Electric Railway Signaling; Its Purposes; Also Past and Present Installations.

BY C. C. ROSENBERG, Signal Engineer, and H. S. BALLIET, Assistant Signal Engineer, Lehigh Valley Railroad, Bethlehem, Pa.

The purpose of automatic signaling on railroads is twofold: (1) To protect trains against collisions, running into open switches, cars fouling main tracks, indicating a broken rail, etc., thereby preventing loss of life and the destruction of equipment and merchandise; (2) facilitating traffic by being able to move more trains and at a higher rate of speed than by the system of spacing trains by time interval; also doing away with human agency, which at times errs in clearing signals, whereas the automatic signal is positive and can be considered a machine to perform a certain duty whenever actuated by a train in the block.

In treating the subject of past and present installations, it is proposed to subdivide it into two parts: (1) To show the method of installation and apparatus from the inception of automatic signaling to a period when they could be considered reliable and beneficial for railroad purposes; (2) to show the improvement in appliances to overcome difficulties experienced by those who were the pioneers in the art, as well as to be able to reduce the cost of operation; at the same time, it is not intended to convey the idea that all of the original devices have been discarded, as there are a number of installations placed in service years ago that are still giving good results, though no doubt later designs are being substituted when repairs are necessary.

In all of the latest developments of mechanism and application the first principles, either separate or combined, are still adhered to.*

PAST INSTALLATION.

It is maintained by some that the credit of inventing the first system of automatic block signals belongs to Mr. Wm. Robinson and by others to Mr. Thomas S. Hall. Both were working upon the development of the system as early as 1866; during this year, Mr. Hall installed on the New Haven Road, near Hartford, Conn., a few signals for experimental purposes; in 1871 he installed a number of disc signals on the New York and Harlem, Boston and Albany and on the Eastern, now part of the Boston and Maine system. During this same year Mr. Robinson put up an experimental installation (clock-work disc) at Kinsua, on the Philadelphia and Erie Railroad. All of the above installations are known as the wire-circuit system, none of which, however, as first installed, worked in an entirely satisfactory manner.

The signal as installed by Mr. Hall was constructed as follows: On top of an iron mast is placed a wooden case, inside of which is a disc of very light weight, consisting of a circular wire frame covered with red silk or serge. The

*At the close of each part of the discourse, there were shown by stereopticon views the various types of mechanism applied for the operation of the different signals in use and the details described.

case has a circular opening in front and back, covered with glass, through which the position of the disc can be seen. When the disc is down, it indicates—Danger, stop; and when it is drawn up, it indicates—Proceed, block clear. In order to more readily distinguish the position of the disc, the case is painted black and the glass in the back of the circular opening, white.

For the night indication, a light is placed back of the circular openings and its rays are directed through the disc, which, being translucent, indicates the position of the signal. The disc is fastened to an arm of a revolving armature of an electro-magnet and is raised to the proceed indication when the magnet is energized; the disc returns to the stop indication by gravity.

The electro-magnet, commonly known as signal magnet, is operated directly by a primary current delivered from a battery located at a suitable place within the block limit by means of a wire placed on poles. The circuit is controlled by a device known as a track instrument, which has levers placed at right-angles to the rails, in such a position that the wheels depress the levers, which in turn causes a second lever to be raised, opening or closing the circuit through a contact spring. The discs are held normally at proceed and the entrance of a train to the block section breaks the circuit in the track instrument, de-energizing a relay, thus dropping its armature, which action opens the battery and de-energizes the signal magnet, thus setting the disc to the stop indication; this indication being maintained until the train passed over a second track instrument located about 2,000 feet within the limits of the next block, the operation of which closed a circuit, energizing the magnets of the relay through the battery, restoring its armature; but the signal instrument remains de-energized until the entire train has passed over the track instrument because its circuit is cut out as long as the contact spring remains closed.

In this system, when a train enters a siding to permit another to pass, and after such train had cleared the fouling-point and the switch was again set for main track, it was necessary to operate what is known as a clearing key in

order to restore the signal to the proceed indication for the following train. On the other hand, in order to protect a train coming from a siding to the main track, a circuit-breaker attached to the switch-point of the outlet turnout opens the circuit of the battery and sets the disc to the stop indication.

The wire circuit does not indicate the presence of a detached car or part of train should it remain in the block, because the forward portion, leaving the block, restored the signal back of the separated portion to the proceed indication.

In an effort to better protect traffic, should failures occur, two signals were installed—the "indicating" and the "stop" signal. The indicating signal was equipped with a blue disc for day and a blue light for night, the normal position being at proceed. About 1,500 feet ahead of the indicating signal was located a home or stop signal, standing normally at stop. An approaching train, when passing the indicating signal, would, if the circuits were intact, set the signal in the caution position in the rear of the train, at the same time causing the electro-magnets to set the stop signal in the proceed indication. The object of this was that if the system were out of order, the stop signal would not clear, and if such were the case, the indicating signal would remain in the caution position, which would be a notice that an approaching train must stop before arriving at the home signal.

Mr. Frank L. Pope made some experiments on the Boston and Lowell Railroad in 1871; he also had a signal on exhibition at the Centennial Exposition in 1876, where he had a section of track submerged in water to show the efficiency of the track circuit. There does not, however, appear to be any data available in either of these installations how he bonded the track, what insulation was employed or how he operated the signal.

In 1872 Mr. William Robinson had issued to him letters-patent, for what was, no doubt, the broadest and most controlling patent ever issued on automatic railroad signaling, the papers covering the invention of the track circuit. He

divided the track into sections, placing a battery at one end and a relay through which to control the signal circuit at the other end. This is the track circuit as used to-day. Mr. Robinson first applied it on the Philadelphia and Erie Railroad early in 1872.

There was another form of treadle or circuit-closing signal device known as the Rousseau system, invented by David Rousseau in 1873. The signal was operated and controlled by a circuit-closer located underneath the rail. The disc when set at right-angles with the track indicated—Danger, stop; and when set with the track, no disc was visible and indicated—Proceed. At night a lamp was placed in the back of the case, which gave a red light for stop and white for proceed. The disc was operated on a revolving vertical shaft controlled by a magnet and its armature. A counterweight which required periodical winding kept the disc from remaining at proceed should the current be cut off. This design of signal was afterwards approved and worked in connection with the track circuit.

In 1879–80 the Fitchburg Railroad adopted the rail (track) circuit signals. This was the first practical installation, other than for experimental purposes, of its kind, and was used in connection with the automatic clockwork signal. The arrangement in this system is as follows: The track battery is placed underground (as a protection against freezing) at the outgoing end of a section; the current is conducted through bonded rails and through a relay at the other or incoming end of the section. This relay controls the local signal circuit through its contact point. At switches, the current (track circuit) is led through a circuit-breaker, which is opened whenever a switch rail is moved. The circuit is also led through the rails of side tracks for a short distance, so that trains entering these tracks are protected, the same as when on the main track, until all of the cars are clear of the fouling point.

The signal is a wooden disc fixed on a vertical spindle, and is turned one-fourth revolution by a weight every time the circuit is made or broken through a relay point. The weight is suspended within a hollow mast and passing over

a sprocket wheel mounted on a shaft, one end projecting from the face of and near the bottom of the instrument, and having a squared end to which is applied a crank or key, thereby enabling the instrument to be wound up periodically. A lamp set on the upper end of the spindle to which the disc is fastened displays indications to correspond to the position of the disc. The local battery which is delivered through the track relay point passes through a pair of electro-magnets (signal magnets) located upon the upper right-hand side of the instrument and above the magnets; pointing to the left is the armature bar, which, as its free end is alternately raised and lowered by the charging and discharging of the signal magnets, releases one of the detent toes and holds the other raised. The office of these toes is to engage and disengage the pawls with the crosshead, which is mounted on a shaft which carries one of the train gears that change the vertical revolution derived from the weight of the horizontal position, this position being required to operate the disc. There is an arrangement applied in such a manner that when the weight has nearly reached the bottom of the pole, the local circuit is automatically broken and the disc will remain in the stop position. The disc when it indicates stop stands at right-angles with the track; when at proceed, edgewise, and is not visible. The signal mast is placed about 150 feet within the block section, so that an engineman, when approaching it and finding the disc in the proceed indication, may see it change to the stop indication.

In the above installation, should a car remain on the track, a rail be removed or broken, bond wires broken off, battery become exhausted or removed, wires broken between track battery and rail or relay and rail, the signal will remain in the stop indication, because the relay magnet will then be demagnetized.

As the clockwork automatic track circuit signal gave good results, it was found advisable about the year 1884 to install what is known as an "overlap," which to a certain extent takes the place of a distant or caution signal. These circuits were first used on the Boston and Albany. The track

and controlling circuits for such an installation are identical to those described on the Fitchburg Railroad, except that another track section is provided, this section extending from 1,000 feet to 2,000 feet into the next block, causing two signals to be held in the stop indication until the rear end has passed the overlap.

The Fitchburg Railroad placed in service 12 miles of electro-pneumatic (semaphore) track (rail) circuit in the year 1879, this being the first installation of this design. At the top of an iron mast, about 24 feet high, is placed a semaphore arm, to which is attached a rod 3 feet long connecting it with a yoke fastened to a piston actuated by compressed air. The air is controlled by an electro-magnet, the armature of which opens and closes a valve. The signal is brought to the proceed position by the attraction of the armature of the electro-magnet becoming energized through a local battery, controlled through the contact point of a track relay. The circuit for this track relay is the same as the one described in connection with clockwork track circuit signals. The de-energizing of the valve magnet closes the valve and opens an exhaust, allowing the air to escape from the cylinder in which the piston is located, a counterweight restoring the signal to the stop position.

In this installation, a circuit-closing spring is attached to the piston rod in such a manner as to open an auxiliary circuit when the signal has returned to the stop position, so arranged as to ring bells at certain switches, which is intended to announce the presence of a train in the block section. This applies, however, to only a few special signals.

The air which operates the arms is applied by a 1-inch pipe, running between the tracks, located below the surface of the ground. At each signal a ¼-inch branch is connected with the main pipe and leads to a reservoir at the bottom of the mast, which holds sufficient supply to make about twelve operations of the arm should the main supply fail. When occasion requires, the supply for each arm can be shut off by a stop-cock, which is located in this branch pipe. Stop-cocks are also supplied in the main pipe about every half mile to assist locating leaks, etc.

The reservoir at bottom of mast is connected with a valve and cylinder by a ¼-inch pipe. The air is placed at 60 pounds pressure, but can be used as low as 40 pounds. It is supplied by a pump of similar construction to that employed for the Westinghouse air brake.

The air first passes through a coil of pipe to cool it, thence into a reservoir with which is connected a blow-off cock to remove the condensed water. From this reservoir it is delivered into the 1-inch main.

In 1884, 13 miles of this design of signal was placed in service on the West Shore Railroad; the same system was also applied on the Pennsylvania Railroad, between Wilkensburg and East-Liberty, the same year. Both of these installations were, however, more complicated than the one described on the Fitchburg.

This system, as operated on the West Shore and Pennsylvania Railroads, embraced features which had not as yet been employed in automatic signaling, viz., the signal being placed exactly at the entrance of a block and having a distant signal for each home signal. The distant signal, being located at the beginning of the preceding section, is placed on the mast carrying the home signal. The upper signal, being the home, is painted red; the lower signal, being the distant, is painted green, having a fish-tail end. The distant refers to the next home signal in advance. The night position is indicated by lamps placed on brackets so fastened to the poles as to throw their rays through a red lens located in the blade grip casting (which are also used as counterweights) when the signals are in the stop position, and through a green lens when the blades are in the proceed position.

There is a line wire between the home and its distant signal, so arranged as to reproduce the movements of the home. There is connected with the home signal, located on the same mast with a distant, a shunt, which cuts out the magnets of the distant signal. This is done to avoid the home signal being in the stop position and the distant in the proceed position. All line wires for distant signals and local battery are grounded to the main air pipe. By this

installation, with a train in the block, there is always displayed a home at stop and two distants at caution.

The signals just described are controlled and operated by compressed air delivered at each mast, as described on the Fitchburg installation. The cylinder has, however, been remodeled and improved. There is an electro-magnet with a diaphragm-like armature to which is attached a long pin; this pin opens and closes a valve called "pin valve." The 60-pound air pressure is constantly maintained at this pin valve, which controls the admission to the cylinder. The piston of this cylinder is connected to the blade directly (as on the Fitchburg) or through a balance lever, and in its normal condition is in the upper end of the cylinder, being held there by the counterweight or balance lever.

When the relay contact is closed, thus delivering current from the local battery through the signal magnet, the armature opens the valve and allows the pressure to enter the cylinder and operate the piston. When the signal magnet is energized the exhaust valve is closed. The breaking of the circuit through the signal magnet causes, the admission valve to be closed and opens the exhaust valve, allowing the signal to return to the stop or caution position by gravity.

In 1887 the New York Central and Hudson River Railroad placed in service 8 miles of double-track disc signals controlled by the wire circuit. This is the first installation where a distant signal is used in conjunction with a home, each being located on a separate mast, both working simultaneously.

Early in 1887, Robert Black placed in service on the Manhattan Elevated Railroad a series of automatic block sections. These blocks are operated under the absolute rule. The semaphore arm, being somewhat shorter than on any previous installations, is fastened to an iron mast and is provided with an iron shield, behind which the arm is hidden when it is in the proceed position. The shield is painted black, so that the proceed position is indicated by the absence of the blade rather than by its position. These signals are controlled by track instruments of peculiar con-

struction, a lever being placed outside of the rail which operates a rocking shaft, which is connected with a series of pipe mounted on pipe carriers. The track-instrument lever is depressed by the tread of the wheels as they pass over it, thus transmitting motion to the blade. The pipe connection leads to a bell crank, through a motion plate located at the foot of the pole and operates an up-and-down rod which moves the blade in the required direction. In order that there may be no unnecessary jar to the various parts, the rocker-shaft arm is supported by means of a rod having on one end of it a strong spiral spring.

PRESENT INSTALLATION.

Very little progress was made in automatic signaling between the years 1887 and 1893. This was probably due to various reasons, viz., traffic conditions did not warrant it; managers evidently considered signals a luxury and not a necessity, or were skeptical as to getting value received, etc. Inventors of signal devices, however, vied with each other in getting out improvements on existing appliances and bringing to the front new devices. In this they were most successful.

In order to describe the different devices brought forward during this period, it will be necessary to begin with the installation of electro-pneumatic automatic block signals on the Pennsylvania Railroad as installed since 1889 (home and distant on same mast), which is the most approved power installation of its kind. The air which is compressed for numerous interlocking plants is also utilized for the block signaling. A track circuit controls the valves for the air operating the arms. The arms are set normally in the proceed position, the top arm being painted red and the lower arm green, with lenses of corresponding colors for night indications.

The circuits controlling these signals are similar to those already described, except that there is no line wire between a home and its distant signal, and are operated by means of a simple and polarized relay combined.

In 1891 discs were placed in service on the New York

Central and Hudson River Railroad, also the Kansas City and Fort Scott Railway. The apparatus and circuits are practically the same as already described, except the normal indication, which is at stop; the approach of a train energizing the signal magnets through the proper circuits, causing the disc to be drawn to one side, thereby indicating proceed; the disc is returned to the stop (normal) indication by gravity. The night indication is given through a glass disc provided at the upper extremity of the revolving armature of the signal instrument. This night glass is of the same color as the cloth disc which gives the day indication. The signal case is provided with suitable openings to correspond.

In connection with these signals, there is a series of indicators or miniature signals, located at side-tracks and cross-over switches, the operation of which indicates the approach or presence of a train in the block. The indicators are held normally at proceed by current taken from the signal circuits to which they are auxiliary, while the disc is in the stop position. When the disc is at proceed, the indicators are at stop because the controlling circuits have been opened, due to the presence of a train.

The Cincinnati Southern Railroad has a number of Union enclosed disc signals in service controlled by a track circuit. The banner is made either of cloth or aluminum, in the center of which is placed a celluloid disc for the night indication. The operation and control of this signal is similar to all other banner signals.

The Lehigh Valley Railroad installed, in 1893, a number of track-circuit signals which differed somewhat from previous descriptions; a red or stop disc is placed at the top of a mast and below it a green or caution, which show normally the stop and caution indication and are set to the proceed indication by the approach of a train. The caution indication is controlled by a wire running from its home through a relay point, the magnets of the relay being in series with home on the same mast with the distant. By this combination, the distant will indicate—proceed, provided there is no train in its home block and the home on

the same mast with the distant is in the proceed indication. These circuits have, however, been improved to some extent in later installations, namely, the caution indication is controlled through a circuit closer located on the magnets of the home signal, so arranged as to be open when the disc is in the stop indication and closed when in the proceed indication.

To assist in making good contacts for this circuit closer and reduce to a minimum the current output from the primary cells which operate the signals, there is arranged a 500-ohm coil, which is cut in automatically when the disc has reached the proceed indication. With this coil in service, there is a current of less than one one-hundredth of an ampere utilized. All switches and crossovers are protected by visible indicators supplied with a red disc.

In all signaling on this road since 1896, track sections are protected with two relays, one at each end of the section, the one at the entrance being 16 ohms resistance and placed in multiple with the track battery; the other, a 4-ohm, at the outgoing end of the section. This installation is carried into effect to meet the various conditions arising from earth currents, which are prevalent. It will be noted that a train entering a track section short-circuits the track battery and the 16-ohm relay, thereby opening the controlling signal circuits. The 4-ohm relay repeats this opening process. All line wires run through switch boxes or circuit-breakers, and go to the end of the block where the governing battery is located.

Signal experts had been working for some time to devise a signal other than the disc type, as some objections had been raised, that under certain conditions the indication could not be readily discerned by enginemen on high-speed trains. It is true the electro-pneumatic semaphore type had been in successful operation for some time. Railroad managers, however, desired a position signal that could be installed either singly or in small groups; for installations of this kind it would not be economical to install power stations.

During the year 1893 an electric motor semaphore signal

was patented by Mr. J. W. Lattig. The first signal of this type was placed in service on the Central Railroad of New Jersey, near Easton, Pa., and operated successfully for several years. The arm is moved from the stop to the proceed position by a $\frac{1}{6}$-horse-power Crocker & Wheeler electric motor, which is supported on a bracket fixed to the side of the mast below the signal arm. When released, the arm is returned to the stop position by gravity.

To operate the motor a potash battery of suitable e. m. f. is used. This battery is placed in a deep well to keep it from chilling under extreme weather conditions. When the motor is operated it winds up a cable, which lifts a counterweight attached to the signal arm, thereby causing the arm to be drawn to the proceed position, and is held there by an electric brake. The motor is controlled through a track circuit similar to other installations. The arms are provided with ball-bearings to reduce the friction and make the various operations more freely.

After this device had withstood the various tests, a number of them were installed on the Illinois Central Railroad in 1896.

The way had now been opened for a new field, viz., to operate signals by other than electro-magnets. The development of the electro-motor since that time has been rapid, and there are to-day in service the following designs:

In the Union electric semaphore many of the possible interruptions to automatically operated signals were anticipated, particularly the placing within an iron pipe, the up-and-down rod connecting the motor and its mechanism with the arm, thereby preventing the freezing at connections in extreme weather. An arm is raised by a motor of low resistance, and is connected to the semaphore in such a manner as to move it to the proceed position. The motor is connected through a set of gears to an endless chain. There is a finger or tooth provided, whereby the arm is raised whenever the circuits are intact, and close the battery through the slot magnets.

The office of the slot magnets is similar to the signal magnets and the air valves described heretofore. The

motor is usually operated by a contact controlled through relay points, and is opened when the arm of the mechanism has reached the full stroke required to set the semaphore arm to the proceed position. Where this signal is installed on the home and distant plan, the distant is controlled by the wireless principle, described in connection with the Pennsylvania Railroad installation. It requires 16 cells of caustic potash battery to operate the same.

By introducing a compound-wound magnet for the slot, the same battery is used to engage the signal and control its operation in addition to furnishing the current for the motor. One motor is required to operate both home and distant blades.

The Wilson motor, semaphore, was next introduced. This application embraces an endless chain, which is set in motion by a $\frac{1}{6}$-horse-power series-wound Crocker & Wheeler motor, through a set of gears.

The clutch magnet is fastened to the up-and-down rod, and travels with it. When current is delivered through the clutch magnet, a contact is closed which starts the motor and the clutch is drawn upward by engaging the tooth of a sprocket wheel in the endless chain. When the semaphore arm has reached the proceed position, the motor current is cut off automatically, and the signal is held in that position by the armature of the clutch magnet remaining engaged. The semaphore is returned to the stop position by gravity. The distant signal is usually operated by a wire running from its home to its clutch magnet and controlled through a circuit-closing spring on the home arm, so as to make it necessary for the home arm to be in the proceed position before the clutch will be energized. By a special shifting apparatus, the motor is thrown into service and the distant blade operated.

Like the home, the distant arm is returned to caution by gravity when the clutch magnet is de-energized. This system requires 12 cells of caustic potash battery to operate each motor. The clutch magnets are controlled through circuits, which get their current from a separate battery, generally 10 cells; this, however, depends largely upon the length of the blocks.

The motor mechanism, known as the Coleman design, is constructed as follows:

A series motor of low resistance operates through a pair of gear wheels, known as a clutch gear, to which is fastened a set of pawls so regulated as to operate the signal arm to the required position. Mounted on a shaft are two loose arms; to the one on the right of the gear is fastened the up-and-down rod of the home, and to the one on the left, the up-and-down rod of the distant signal. The arms are engaged with the pawls by an armature. The clutch magnets are permanently fixed to the motor mechanism frame. When there is a current delivered through these clutch magnets, the armature is engaged, which allows the arm to be moved into the position required to move the semaphore arm to the proceed position. There is a second armature on this clutch magnet which closes the motor circuit and controls the operation of the same. Attached to the arm operating the blade is a rod controlling a circuit-breaker which stops the motor as soon as the blade movement is completed. The signal is held in the proceed position as long as there is current through the clutch; it returns to the stop position by gravity. The battery arrangement is similar to that of the Wilson motor signal.

There is an older design of the Coleman motor mechanism in which the clutch is attached to the moving arm instead of being stationary; otherwise the mechanism and its operation is similar to the one just referred to.

All of the motor signals heretofore mentioned are in service on what is known as the two-position signal, viz., the arm in the horizontal position or at right-angles from the mast, as seen from an approaching train, denotes stop; when at 45°, 60° or 90° below the horizontal (according to the standard practice), denotes proceed. At night this indication is reproduced by a light through the lens.

There is in service a three-position electric motor signal, that is to say, one semaphore arm can be set at three different positions, viz., horizontal, Stop; 45° below the horizontal, Caution; 90° below the horizontal, Proceed. Each signal is controlled by a track circuit immediately in front

of it, as already noted, but the control for the distant position of the signal in the rear is maintained through the medium of a line wire located on poles.

The signals are worked by electric motors of $\frac{1}{12}$-horsepower, one at each signal. The motor moves the signal arm by means of an apparatus analogous to the electric slot, termed the slot instrument. This instrument consists of a sleeve, which is directly connected with the up-and-down rod of the blade, inside of which is fitted a rod. This rod has a number of teeth so arranged and located as to engage the teeth of a pinion driven by a motor. At a given point the sleeve is provided with an opening, through which the armature of the slot magnet locks it (the sleeve) to the rod just mentioned. When the slot magnet is energized, owing to the track relay being engaged, the motor will operate the blade to the proceed position, it being held there by the lock introduced by the slot armature. When the slot armature is disengaged, the arm returns to the stop position by gravity, the lock in the up-and-down rod having been withdrawn. In order to raise the signal, the motor transmits its power through a series of gear wheels to a pinion which has a given number of teeth omitted, so as to make it possible to return the arm to the stop position without running the motor mechanism backward.

The various positions of the arm are maintained by pawls, so arranged as to hold the weight of the semaphore arm as long as the slot magnet is engaged. In order that there may be no undue strain to the mechanism when the arm is returned to the stop position, a dash pot or air cushion is provided.

The circuits operating the motor and energizing the slot magnet are controlled by the movement of the up-and-down rod, operating the semaphore arm.

Some of the motors on the installation of the P. F. W. and C. Railway are operated by six type 5D accumulator cells, four signals being located on a bridge, all of which feed from this battery. These cells, as well as track battery (also storage) for a distance of 35 miles, are charged by a power circuit located on poles. Still another installa-

tion on this system has storage of the same type charged by primary cells.

On the Alleghany Mountains, near Altoona, Pa., is found the only installation having two distant signals on the same mast with the home. On account of the heavy descending grade, it is important that enginemen have as much information of the condition of the blocks in advance as can be given. As in all other Pennsylvania Railroad installations, the upper or stop signal relates to the block directly in advance; the distant immediately below the home refers to the second, and the lower, to the condition of the third. It will thus be seen that ample information is given to successfully operate at high speed the many heavy trains using this line. Line wires located on poles control the distant for the third block. The entire installation is of the electro-pneumatic type controlled by track circuit.

The largest single track automatic block signal installation in service is on the Cincinnati, New Orleans and Texas Pacific. All of the later types of signals are here represented. No distant signals are used, the overlap being substituted. All masts are set 210 feet within the block section, so that the enginemen may see the signal move from the proceed to the stop position. The circuits are maintained through line wires located on a pole line. Caustic potash and bluestone battery are used for the various circuits.

On the Southern Pacific there are in service a number of electric motor signals of the Union type to protect single track movement; no distant signal is used, the overlap system being in service. The wires controlling these signals are placed on a pole line. All masts are set directly at the entrance to the block. Signals for both directions are directly opposite. The overlaps are about 800 feet long. The operation of this system is similar to that on the C. N. O. and T. P. Railroad. The motors are operated by four cells of portable storage battery, and are charged about once a month, by taking them to the several power plants, installed at specified points along the line; these plants are also used for other purposes.

There is in service on the Lehigh Valley Railroad a sin-

gle-track automatic block system, in which the home and distant signals are placed on the same mast at the entrance to a block. The signal for the opposing direction is from one-half to one mile distant. These signals are controlled by wires placed on a pole line. They are operated by caustic potash battery for signals and bluestone for track circuits. In this installation there is always a piece of track equivalent to one block between two opposing trains, which is guarded by a signal in either direction. The distant signal is substituted for the overlap previously mentioned.

Until 1899 but two colors were available for night indications that could be distinguished at a distance, viz., red for stop; green for caution. In a few cases, however, green was substituted for proceed, and either a combination of red and green side by side or red applied for caution; in the latter case, the day indication being a green blade and a red light at night.

To the New York, New Haven and Hartford Railroad belongs the credit of taking the initial step by adopting a yellow lens for the distant night indication. In the year 1899 they placed in service red for stop, yellow for caution, and green for proceed, which practice is fast coming into favor.

The Chicago and Alton Railroad, in 1900, installed a number of electric motor semaphore signals, standing normally at stop. The motors are operated by a caustic potash battery. The home or stop signal is painted white with a black stripe near the outer end and parallel to it. The distant or caution blades are fish-tail and painted yellow with two black stripes. These stripes correspond with the shape of the fish-tail. The night indications are red for stop and yellow for caution, with green for proceed. In this installation the distant signal is placed on a separate mast a suitable distance in the rear of its home signal.

The distant signals are set to the proceed position at a point 1,200 feet before reaching it; also at the same time the corresponding home. Audible indicators (bells) are placed at all switches and announce the presence of a train when it sets the distant and its home to the proceed posi-

tion, and will indicate until the block is clear. The distant signals are controlled by a polarized relay, operated in conjunction with line wires.

The Central Railroad of New Jersey, and Delaware, Lackawanna and Western, in 1900, installed a number of electric motor signals, home and distant on the same mast. The semaphore arms stand normally at proceed; a simple and polarized relay is in use, the simple side of the relay controlling the home signal, and the polarized side its distant through the track by introducing a pole changer on the up-and-down rod of the home signal; this pole changer reverses the polarity of the track battery, thereby giving the distant indication after the home has resumed the proceed position.

In 1900 there was installed on the Boston Elevated Railroad a system of electro-pneumatic signals, such as already described, except that they are controlled by a special track circuit arrangement. This is an electric railroad, and in order to make it possible to operate a track circuit, the one rail is used for a return power circuit and is reinforced by a copper wire. Polarized relays are so arranged as to use the return rail and an independent wire for the return circuit. The relays are actuated similar to other track circuit installations, except in this case there are no local or track batteries. The contacts of these relays control the electro magnets of the pin valves, as explained in regular pneumatic installations. At each home signal which stands normally at proceed, there is a trip arranged to automatically open the air pipes on the train and apply the brakes should the motorman neglect to obey the stop indication. Each signal is placed 180 feet in the rear of the beginning of its control track section, or in other words, the front end of a train must be 180 feet by the home signal before it will set it to the stop position. This is necessary in order that the rear car may be beyond the trip, which automatically stops a train which may attempt to pass a home signal.

A number of railroads have installed what is known as the semi-automatic or slotted signal. The most simple design is an arrangement by which the up-and-down rod is

made or broken by the intervention of a tooth controlled by an electro magnet. The upper rod is arranged so as to allow the lower rod to travel within its hollow part. A suitable notch is cut to allow the armature tooth to engage the rod when current is delivered through the magnet, thereby allowing the leverman to pull the signal to the proceed position. The slot magnets are controlled through a track circuit relay, and as soon as a train enters the section, demagnetizes it, thereby releasing the tooth, allowing the arm to return to the stop position by gravity. There are many installations in which a circuit breaker is so arranged as to make it necessary for the leverman to raise a latch on an interlocking lever before the arm can be electrically engaged and pulled to proceed. Still another arrangement is where the proceed signal cannot be given until a train is actually approaching either the distant or the home signal. This is accomplished by track circuit relays, engaging the slot at specified points.

In this system all slotted semaphores are held normally at stop. In all cases described, a train, after passing under a home signal, keeps the slot magnet de-energized, making it impossible for the leverman to operate the arm, although the lever is free to be moved. It takes from eight to twelve volts to accomplish this function, depending largely upon the length of the sections and minor conditions. In addition to these so-called electro-mechanical slots there is an electric slot in service. This is used in connection with the All-Electric interlocking. The magnet of this slot is of high resistance, and so arranged that an approaching train will receive a proceed signal if the slotted or block section is clear. The current (usually 110 volts) is supplied by a generator or storage battery, the arrangement of circuits being similar to those above described.

In 1901 a local power signal was invented, operated by means of compressed liquid carbonic acid gas, supplied in tanks. In this design, unlike previous descriptions, the power supply is localized, each signal mast having its distinct reservoir. The long-established principle of a separate supply of current for each circuit is here carried into effect.

A cylinder about 5 inches long, constructed of suitable metal to prevent rusting, and supplied with a piston of the same material, operates the semaphore arm, and is directly connected to the up-and-down rod. A port of suitable design is placed between the reservoir and the cylinder, the office of which is to control the supply of gas, and is operated by one of the armatures of a double and electro magnet. When this magnet, commonly known as the clutch, is energized, it opens the port, allowing the gas supply, usually 50 pounds, to enter the cylinder, which causes the piston to move the arm to the proceed position. As soon as the arm has reached this position the port is closed automatically by the other armature, thereby allowing the gas supply in the cylinder to be exhausted. This armature also holds the signal in the proceed position. When the clutch is de-energized, the arm returns to the stop position by gravity. The control of the clutch is affected by means of the track circuit, as all other installations. The clutch is operated by primary cells, and requires about 5 volts for blocks 1 mile in length.

Liquid carbonic acid is a commercial article, and for signal purposes is supplied in tubes or tanks about 7 feet long, 8 inches in diameter, each containing about 50 pounds. This gas is chemically pure CO_2, liquefied by means of high pressure, assisted by low temperature, as received in the reservoir and compressed to 900 pounds to the square inch, which reduces it to a liquid form.

The number and type of signals in use on the various railroads in this country are classified as follows:

Enclosed disc	1,894
Clockwork disc	1,041
Electro-pneumatic	3,420
Motor	7,346
Electro gas	248
Total	13,949

The writers of this article have endeavored to define the various designs and systems in a concise form, without entering too closely into detail; they are indebted to the

various technical papers and authors of works on signaling for some of the detailed data required in clearly defining the functions of the different systems.

ARTIFICIAL CAMPHOR.

The manufacture of pure artificial camphor upon a commercial basis has been discovered by Mr. E. Callenberg, of Germany, technically known as chlorhydrate of terebinth. This substance possesses many peculiar properties, which will render it of great value for many commercial purposes, the most important of which is that it is soluble in nitro-glycerine; and as it reduces the maximum temperature of this dangerous substance during explosion, it is considered that it will do much to render considerably more safe the manufacture of high explosives such as nitro-glycerine. Not only does it reduce the temperature of explosion, but it lowers the freezing point of the substance to a very marked extent as well. Pure nitro-glycerine freezes at + 8 deg. centigrade, but when a 3 to 5 per cent. solution of the chlorhydrate of terebinth is added, the freezing point drops from —10 deg. to —15 deg. centigrade Furthermore, guncotton and many other soluble explosives can be easily dissolved at a low temperature in a solution of chlorhydrate of terebinth and nitro-glycerine, the resulting substance being a highly improved quality of gelatine-dynamite.—*Scientific American.*

ALUMINUM AND BAUXITE.

The report on aluminum and bauxite for 1902, by Dr. Joseph Struthers, has just been issued by the United States Geological Survey. The production of aluminum in the United States during 1902 was approximately 7,300,000 pounds, as compared with 7,150,000 pounds in 1901, the sole producer being the Pittsburg Reduction Company, which has large plants in operation at Niagara Falls and at Shawingan Falls, Quebec, Canada, and is installing a large plant on the St. Lawrence River, near Massena, N. Y.

The chief use of aluminum is for the transmission of electrical currents and for alloys possessing exceptional physical and chemical properties, though a considerable part of the output is manufactured into domestic articles of various kinds. Two growing uses of the metal are for lithographic work and for the production of intense heat by the combustion of the metal as powder.

The production of bauxite during 1902 amounted to 27,274 long tons, as against 18,905 long tons in 1901. Georgia yielded the greater bulk of the product, the remainder coming from Alabama and Arkansas. The consumption of bauxite in 1902 amounted to 43,112 long tons, as compared with 36,218 tons in 1901.

The domestic production of alum and aluminum sulphate in 1902 amounted to 88,614 short tons, valued at $2,238,171, as compared with 82,496 short tons, valued at $2,026,554 in 1901. The imports in 1902 were valued at $16,808, as compared with $20,781 in 1901.

The Induction Motor and Its Engineering Capabilities.*

[*A Thesis Presented to the University Faculty of Cornell University for the Degree of Doctor of Philosophy.*]

By George L. Hoxie.

Part One.

THE INDUCTION MOTOR.

Definition.—The induction motor, as its name implies, is a motor that depends for its operation upon the principles of "induction." As generally used, this term means the production of an effect at some point by a cause located elsewhere, no apparent mechanical connection existing between the cause and the effect.

Thus, given an electric charge on a conducting body, if a second conductor be brought into the neighborhood, induced charges, of opposite signs, will appear on those surfaces of the second body which are nearest to, and most remote from, the originally charged body.

Also, if a current be established in one of two neighboring closed conducting circuits, a current, called an induced current, will flow momentarily in the second circuit.

Or, if a magnet be created in the vicinity of a mass of soft iron, induced magnetic poles will appear on the latter.

Many similar examples of induction might be given. Any motor that depends primarily upon such phenomena for its operation may be properly termed an induction motor.

Practical Form.—Several varieties of purely induction motors have been devised, but only one possesses any practical interest. In this class, the magnetic forces produced by the field due to an induced, or secondary, current reacting

* The writer wishes to thank Prof. Harris J. Ryan for suggestions and advice received prior to the inception of this thesis, and from time to time during the progress of the work.

Also to acknowledge his indebtedness to several friends, through whose kindness it was possible to obtain the data of construction and performance which form a part of this paper.

upon the field produced by an inducing, or primary, current, are made to do work.

Both primary and secondary currents are of necessity alternating, since it is only by a change in one current that another may be induced. It is also necessary, in order to get a continuous rotary motion, that the currents present should be polyphase currents. This does not necessarily imply that polyphase currents should be supplied to the motor, although it is usually best that this should be done.

The elementary theory of induction motors is quite simple, but an extended study of their behavior involves the consideration of some very complex relationships, and is correspondingly difficult. In fact, such a study cannot be made at all without the use of approximations which affect to a greater or less degree the accuracy of the result. This state of affairs is not indeed peculiar to the induction motor. Hardly any of Nature's phenomena are so simple that a mathematical study of them can be entirely complete. Obviously the results of such a mathematical investigation are only correct to the same degree as were the original assumptions. It is therefore of the utmost importance that one should determine as accurately as possible the degree to which such approximations as are necessary are likely to affect the final result.

Study of a Particular Motor.—Before taking up any theoretical matters connected with the induction motor, it will be well to make a very careful study of a particular motor, not from a mathematical standpoint, but with a view of actually determining what goes on in the iron and copper of which it is composed. Such a study will serve to make clear the effect of some of the customary approximations used in the mathematical theory of the motor, and will enable one to form a fairly correct idea as to their propriety.

The motor chosen for this detailed study is one for which the writer was able to obtain nearly all of the electrical dimensions. Its specifications are as follows:

Horse-power	75
Revolutions per minute	250
Outside diameter of primary core	40 in.

Inside diameter of primary core	32·09 in.
Outside " " secondary "	32 "
Inside " " " "	26 "
Gross laminations parallel to shaft	10·5 "
Ventilating ducts " " "	1 "
Net laminations " " "	9·5 "
Volts primary pressure	220
Phases	3

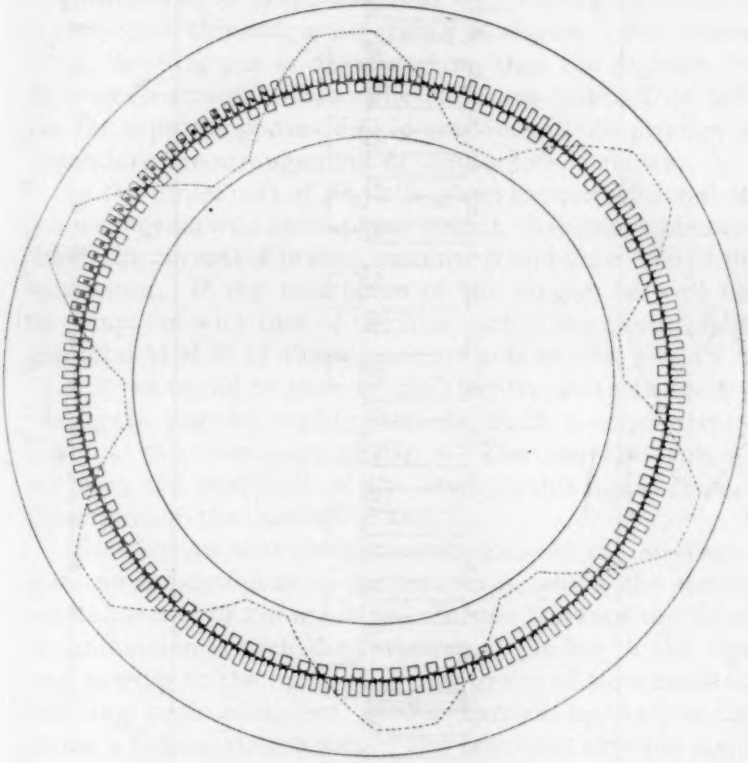


FIG. 1.

Poles	12
Primary connection	delta.
" circuits per phase	1
Number of primary slots	144
Dimensions " "	·36 x 1·6 in.
" " conductors	1 x ·6 "
Primary conductors per slot	4
Secondary connection	sq. cage.

Secondary slots	99
Width of secondary slots	·55 in.
Total depth of secondary slots	·58 "
Secondary conductors per slot	1

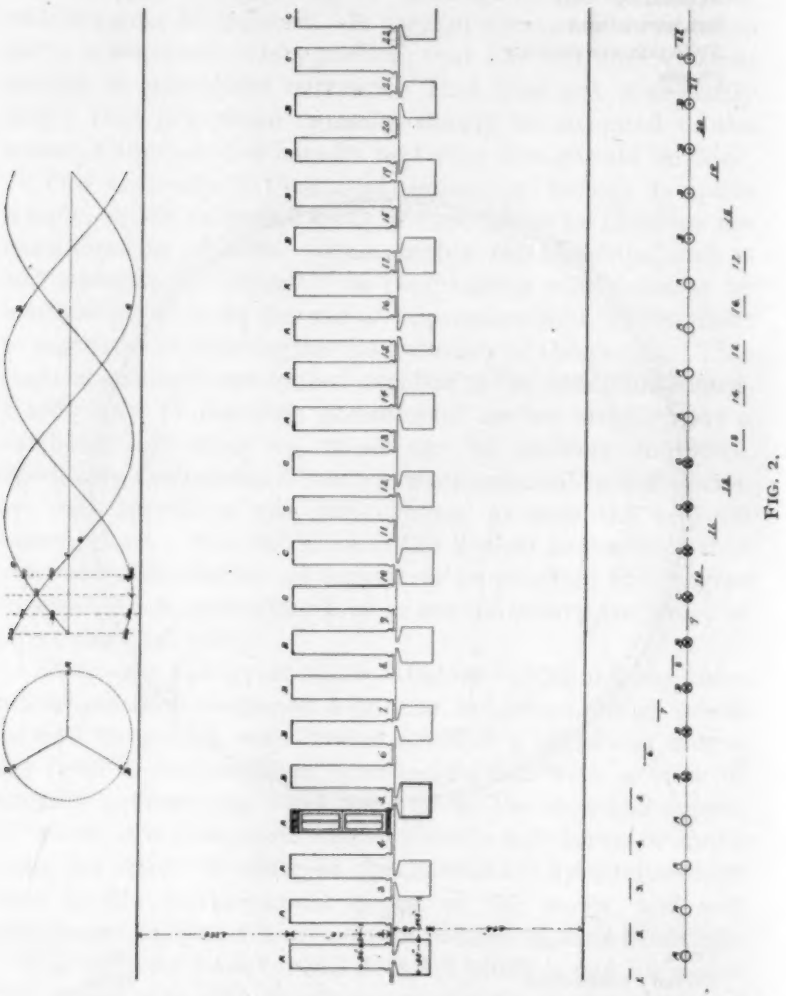


FIG. 2.

The magnetic circuit or flux-carrying parts of this motor are drawn to scale in *Fig. 1.* Since there are three phases and twelve poles, there are four slots per phase per pole, the phases being grouped as indicated by the letters *aaaa, bbbb,*

cccc, *aaaa*, etc., in *Fig. 1*. The magnetic field produced by the three currents at a particular instant in the operation of the motor is shown graphically in *Fig. 1* by a dotted line. The bore of the primary is taken as the axis of abscissas, and since this is a circle the resulting curve of flux distribution is a little distorted. It will be noted that six poles are positive and six negative, a total of twelve.

Distribution of Magnetism.—In *Fig. 2* an enlarged view of a section of this magnetic circuit is shown. For convenience the diagram is developed so that the primary bore becomes a straight line. The slots are lettered as before for the separate phases, and in one slot of both primary and secondary the arrangement of conductors is shown.

In the upper part of *Fig. 2* is given the conventional sine-wave diagram for a three-phase circuit. Selecting the instant when the current *A* is zero, currents *B* and *C* are ·866 of their maximum. If the reluctance of the air-gap be very large as compared with that of the iron part of the circuit, so that the total M.M.F. of these currents acts at the air-gap, this M.M.F., as found at each of the twenty-two teeth shown in the figure, may be readily plotted. Such a construction is found at the lower part of *Fig. 2*. The conventional signs between the positions of the teeth in this figure show the directions of the currents *B* and *C*.

It is obvious that the phase relations of the sine curves give no indication as to the manner in which the currents are connected to the machine. In this instance the scheme of connection is such that, starting at the left of the figure and moving to the right, each new group of slots reached is carrying such a current as was carried by the preceding group a little earlier in time. The resultant effect is similar to that of a motion from right to left of both currents and magnetism.

Method of Plotting.—In the case chosen for *Fig. 2*, where one current is zero and the other two are equal, it is a very simple matter to compute the M.M.F. acting through each tooth since all the flux paths are symmetrical. It is not always so obvious, however, how this should be done, and it is perhaps desirable to show that the method followed is a proper one for any current distribution.

It will be assumed that in any magnetic circuit under consideration the conditions are approximately as follows:

(1) The magnetic circuits are formed in two concentric rings of laminated metal, as in *Fig. 2*.

(2) The total reluctance of any circuit is located in the air-gap between the rings.

(3) All magnetic circuits are parallel to the paper.

(4) The magnetic fields are set up by currents in conductors which lie in the slots of the outer ring, and which are perpendicular to the plane of the paper.

(5) For each current in a single slot there are present similar currents at equidistant points around the circumference, the total number in each case being equal to the number of magnetic circuits.

A general case fulfilling these conditions is illustrated in *Fig. 3*. In this figure the current in conductors A_1, A_2, A_3 and A_4 is 200 amperes; that in conductors B_1, B_2, B_3 and B_4 is 100 amperes; and in conductors C_1, C_2, C_3 and C_4 is 50 amperes. It is required to find the manner in which the flux is distributed around the air-gap in this figure.

Since the reluctance of the iron is assumed to be zero, that of the air is the only item limiting the flux established by a given M.M.F. As the permeability of air is unity, a given change in M.M.F. will always produce the same change in the flux present, no matter what may be the flux density. Under these circumstances we may make use of the principle of "superposition;" that is, the field due to any combination of currents is equal to the geometrical sum of the fields which would be produced by each current taken separately. Since all fields are radial at the air-gap in the present instance the geometrical sum is also the algebraic sum.

Selecting the four conductors A_1, A_2, A_3, A_4, it is evident that, taken alone, equal fields would surround each, and that these fields would lie in the quadrants formed by the lines $A'A'$ and $A''A''$. Since the flux in any case must cross the air-gap twice, it will encounter an equal reluctance by any path. The flux density is therefore uniform over the entire circumference, and is such as would be produced by 100

ampere turns of M.M.F. applied at each point of the air-gap. Let us call flux leaving the inner ring positive, and flux entering the inner ring negative. Then in *Fig. 3* there are due to currents in the *A* conductors only:

From A_1 to A_2	. . . . .	— 100 A. T.
" A_2 to A_3	. . . . .	+ 100 A. T.
" A_3 to A_4	. . . . .	— 100 A. T.
" A_4 to A_1	. . . . .	+ 100 A. T.

Similar reasoning will show that with current in the *B* conductors only, we should have:

From B_1 to B_2	. . . . .	— 50 A. T.
" B_2 to B_3	. . . . .	+ 50 A. T.
" B_3 to B_4	. . . . .	— 50 A. T.
" B_4 to B_1	. . . . .	+ 50 A. T.

or with only the *C* conductors carrying current the M.M.F. at various points would be:

From C_1 to C_2	. . . . .	— 25 A. T.
" C_2 to C_3	. . . . .	+ 25 A. T.
" C_3 to C_4	. . . . .	— 25 A. T.
" C_4 to C_1	. . . . .	+ 25 A. T.

When all the currents are present simultaneously an algebraic addition gives:

From A_1 to B_1	. . . . .	— 25 A. T.
" B_1 to C_1	. . . . .	— 125 A. T.
" C_1 to A_2	. . . . .	— 175 A. T.
" A_2 to B_2	. . . . .	+ 25 A. T.
" B_2 to C_2	. . . . .	+ 125 A. T.
" C_2 to A_3	. . . . .	+ 175 A. T.

and so on.

The dotted lines with arrow-heads, which are drawn in *Fig. 3*, indicate graphically this air-gap distribution, one line crossing each 15° for each 25 ampere turns. No attempt has been made to show the exact distribution in the iron. The following notes may be made upon this figure:

(1) No flux circuit is formed that does not include one of the *A* conductors, these carrying a larger current than the others.

(2) Some flux travels by a route that includes all the conductors, A, B, C, of one group.

(3) The flux does not divide symmetrically between one group, A_1, B_1, C_1, and the adjacent groups, as A_2, B_2, C_2, but the flux belonging to one group extends almost over to the conductor C of the next group.

It should, of course, be borne in mind that *Fig. 3* represents a very special case of flux distribution, and particularly that the conditions practically preclude leakage.

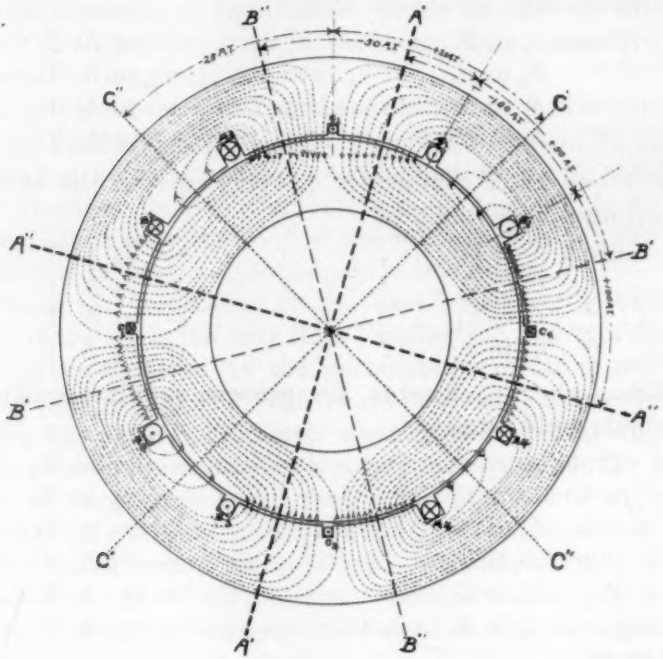


FIG. 3.

Actual Distribution in Motor.—In the actual motor the reluctance of the iron part of the magnetic circuit is not zero, but except for the teeth such reluctance is relatively small. It may be assumed, without great error, that taking the teeth and air-gap together, nearly all of the reluctance of any magnetic path is contained therein. The flux, or M.M.F., at each tooth may then be determined by the method

of the preceding paragraph without great labor. The only error of any importance in such a determination lies in the assumption that the flux is proportional to the M.M.F. The magnitude of this error will be estimated later.

In order to make the problem as concrete as possible, it is assumed that each conductor will carry a sine-wave of current, having an effective value of 45 amperes. The results obtained, being proportional to the current, will serve equally well for any current value. A current of 45 amperes was taken because, as nearly as could be estimated from experimental data on other motors, 45 amperes was the most probable value for the magnetizing current of this motor.

It is assumed that the secondary bars are present, but are unconnected at the ends, so that no secondary current may flow. The flux distribution will be determined for intervals of 15°, measured on sine curve *A*, *Fig. 2*, and starting with the phase angle of *A* equal to zero. The successive currents in conductors lying in the *A* slots will, therefore, be, 0, ·259, ·5, ·707, ·866, ·966, ·1, ·966, etc., where the maximum value is unity and the interval is 15°. With four conductors per slot, each carrying 45 effective amperes, the total current per slot is 180 effective, or 254 maximum, amperes, and the various momentary currents are as follows:

PHASE ANGLE OF PHASE *A*	CURRENT IN PHASE. *A*	*B*	*C*
0°	0	220	220
15°	65	245	180
30°	127	254	127
45°	180	245	65
60°	220	220	0
75°	245	180	65
90°	254	127	127

The net M.M.F., applied to the teeth and air gap by these currents, is set down in the table on the following page for the teeth positions, shown in *Fig. 2*.

It may be noticed from this table that there is a regular progression, from tooth to tooth, of the zero line of flux. The position of this line is dotted across the table.

The point of maximum flux moves in the same direction, but not regularly, and is noted on the table by a jagged line

Ampere Turns at Tooth No	Phase Angle of Phase "A."												
	0°	15°	30°	45°	60°	75°	90°	105°	120°	135°	150°	165°	180°
1.	880	982	1016	982	880	720	508	262	0	-262	-508	-720	-880
2.	880	917	889	802	660	475	254	17	-220	-442	-635	-785	-880
3.	880	851	762	622	440	229	0	-229	-440	-622	-762	-851	-880
4.	880	785	635	442	220	17	-254	-475	-660	-802	-889	-917	-880
5.	880	720	508	262	0	-262	-508	-720	-880	-982	-1016	-982	-880
6.	660	475	254	17	-220	-442	-635	-785	-880	-917	-889	-802	-660
7.	440	229	0	-229	-440	-622	-762	-851	-880	-851	-762	-622	-440
8.	220	17	-254	-475	-660	-802	-889	-917	-880	-785	-635	-442	-220
9.	0	-262	-508	-720	-880	-982	-1016	-982	-880	-720	-508	-262	0
10.	-220	-442	-635	-785	-880	-917	-889	-802	-660	-475	-254	-17	220
11.	-440	-622	-762	-851	-880	-851	-762	-622	-440	-229	0	229	440
12.	-660	-802	-889	-917	-880	-785	-635	-442	-220	-17	254	475	660
13.	-880	-982	-1016	-982	-880	-720	-508	-262	0	262	508	720	880
14.	-880	-917	-889	-802	-660	-475	-254	-17	220	442	635	785	880
15.	-880	-851	-762	-622	-440	-229	0	229	440	622	762	851	880
16.	-880	-785	-635	-442	-220	-17	254	475	660	802	889	917	880
17.	-880	-720	-508	-262	0	262	508	720	880	982	1016	982	880
18.	-660	-475	-254	-17	220	442	635	785	880	917	889	802	660
19.	-440	-229	0	229	440	622	762	851	880	851	762	622	440
20.	-220	17	254	475	660	802	889	917	880	785	635	442	220
21.	0	262	508	720	880	982	1016	982	880	720	508	262	0
22.	220	442	635	785	880	917	889	802	660	475	254	17	-220
23.	440	622	762	851	880	851	762	622	440	229	0	-229	-440
24.	660	802	889	917	880	785	635	442	220	17	-254	-475	-660

of dots. A line made up of dashes, and dividing each flux group into equal parts, is also drawn across the table. This line is straight, and indicates a uniform progression of the

flux. The total quantity of flux varies somewhat, and this variation is indicated by the numbers 7040, 7104, 7112, 7104, 7040, etc. These numbers are computed upon the assumption that the flux and M.M.F. are proportional, and they are more nearly equal to each other than this assumption is to the truth, so that for all practical purposes the following conclusions may be regarded as reached for this motor:

(1) The total quantity of flux is constant.

(2) The points of zero flux move around the circumference at a uniform velocity.

(3) The points of mid-flux move around the circumference with a uniform velocity.

(4) The points of maximum flux move around the circumference, but not with a uniform velocity.

The points of maximum flux move with twice the velocity of the points of zero flux, but are moving only half of the time, so that the net rate of progression is the same for either.

From facts Nos. 1, 2 and 3, we may state the following —which is true at least for this particular motor.

The effect of the changing magnetism upon the primary conductors is practically the same as would be produced if the primary were on open circuit and the secondary were replaced by a rotating field having twelve poles, each pole having a flux distribution varying from a maximum at its center to zero at a point midway between poles.

That is to say, there has been produced a *changing field similar to, and practically the same as, a rotating field.*

Graphical Construction.—In *Fig. 4* the flux distribution, as indicated by the accompanying table, is shown graphically. The dotted parallelograms, marked 1 to 22, represent the position of the teeth of *Fig. 2*. The short horizontal lines across these indicate by their distances from the axis, the successive M.M.F.'s acting at each tooth, and the dotted lines joining these horizontals show the distribution over a portion of the air gap, for eight different instants, $\frac{1}{24}$ of a cycle apart.

At the lower part of *Fig. 4* are drawn curves showing the magnetic cycles through which typical teeth, Nos. 9, 10

and 11, must continually pass. These values were determined from the upper figure. There are sine curves, as was to have been expected. They show that the limits of

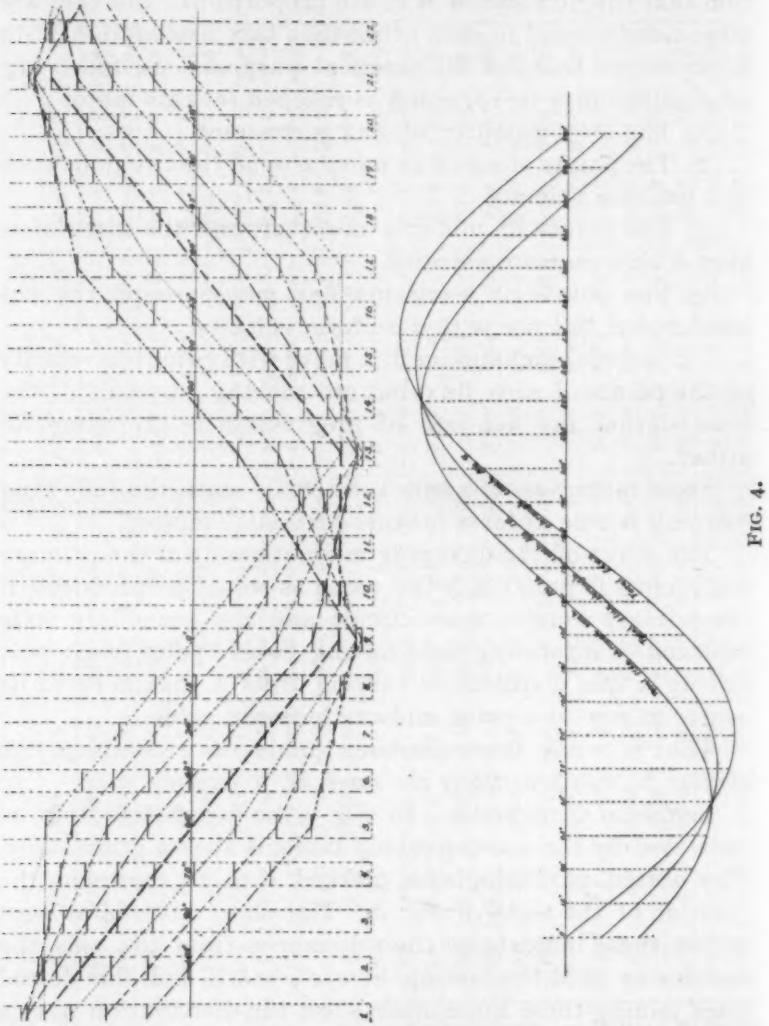


FIG. 4.

magnetic density, and the hysteresis losses, are not the same in different teeth. The three sine-waves shown represent, however, the entire variation in the machine under discussion.

The counter E.M.F. induced in a single conductor of the primary circuit should, under the assumed conditions, be a sine-wave. It is of interest, however, to derive this from the determined fluctuations of the field, and to determine independently the phase and quantity relationships existing between the E.M.F.'s induced in conductors lying in four adjacent slots of a single-phase group.

This was done in the following manner: Referring to *Fig. 2* and to the table of M.M.F. distribution, quantities

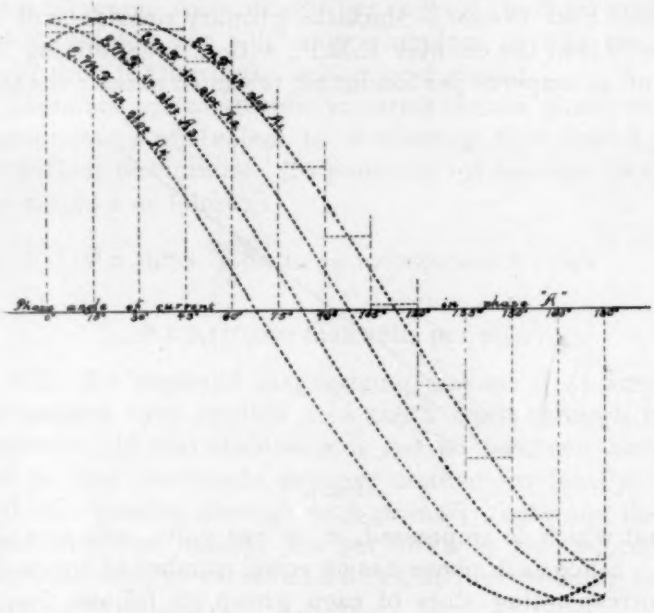


FIG. 5.

proportional to the flux actually surrounding the slot between teeth Nos. 13 and 14 were set down for phase angles of phase *A*, of 0°, 15°, 30°. . . . . 180°. Since these values occur $\frac{1}{24}$ of a cycle apart, the difference between two successive values is proportional to the average E.M.F. induced in a conductor lying in such a slot during that part of a cycle.

These differences were carefully determined, and in *Fig. 5* they are plotted as horizontal lines, 15° in length, and

at appropriate intervals. The curve A was sketched through these horizontals in such a manner that each horizontal should be an average ordinate for that part of the curve lying between the same vertical lines. Curves A_2, A_3 and A_4, were plotted in a similar manner, though their construction lines are not given in *Fig. 4.*

As nearly as could be determined by this graphical method all the curves are sine curves, and are equal. This, of course, was to be expected, and serves as a check upon the numerical work.

Total Flux Present.—Since the primary resistance of the motor is low, the counter E.M.F., with a magnetizing current of 45 amperes per conductor, is almost exactly the same

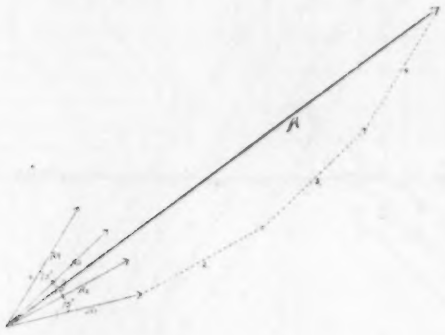


FIG. 6.

as that which is impressed, or is 220 volts, effective pressure. Since each phase has an equal number of conductors in corresponding slots of each group, it follows that the E.M.F. induced in the conductors of one slot of each group must bear to 220 volts the same relation that the E.M.F. curve A, for example, bears to the sum of curves A_1, A_2, A_3, A_4.

But the E.M.F.'s of *Fig. 5* are not in phase, and their sum is less than four times either. In other words, there are times when the E.M.F. generated in certain conductors of one phase is opposed to that generated in others of the same phase. There is then a *differential action*, as is the case in many A. C. dynamos.

Obviously the magnitude of such a differential action will depend upon the space occupied along the primary bore, by a group of conductors belonging to a single phase, or it will be greater as the number of slots per phase and pole is increased. In this case the situation is illustrated in *Fig. 6*, where A_1, A_2, A_3, and A_4, represent the E.M.F.'s in each set of slots, and A represents the E.M.F.'s of the entire phase. Each component factor must be 51·8 average volts, if the sum is to be 198 average, or 220 effective volts, or there are lost 9·2 average volts, or 4·65 per cent. of the total pressure. The actual flux per pole must, therefore, be 4·65 per cent. larger than if differential action were absent.

There are 192 conductors in series in each phase, and the magnetism is equivalent to a rotating field making 250 revolutions per minute. To generate 198 average volts, the flux must be as follows:

$$\Phi \times 192 \times \frac{250}{60} \times 12 = 19800000000 \times 1{\cdot}046$$

or,

$$\Phi \times 2{,}156{,}000 \text{ maxwells per pole};$$

or with the assumed magnetizing current of 45 amperes, one ampere turn applied at a tooth sends through it 304 maxwells. In this discussion it has so far been assumed that no flux surrounds primary conductors locally. The total flux passing through each primary tooth and the corresponding flux density are set down in the succeeding tables, the current values and flux distribution being as previously determined:

FLUX DENSITIES IN TEETH.

Tooth No.	Phase Angle of Phase A. 0°	15°	30°	45°
6	62800	45200	24100	1600
7	41800	21700	0	21700
8	20800	1600	24100	45200
9	0	24800	48400	68500
10	20800	42000	60400	74600
11	41800	59100	72200	80800
12	62800	76200	84500	87000
13	83600	93200	96500	93200
14	83600	87000	84500	76200
15	83600	80800	72200	59100

Tooth No.	Phase Angle of Phase A. 0°	15°	30°	45°
16	83600	74600	60400	42000
17	83600	68500	48400	24800
18	62800	45200	24100	1600
19	41800	21700	0	21700
20	20809	1600	24100	45200
21	0	24800	48400	68500

FLUX AT TEETH.

Tooth No.	Phase Angle of Phase A. 0°	15°	30°	45°
6	200600	144400	77200	5200
7	133700	69600	0	69600
8	66800	5200	77200	144400
9	0	79600	154400	218800
10	66800	134400	193000	238600
11	133700	189000	231600	258700
12	200600	243800	270200	278700
13	267500	298500	308800	298500
14	267500	278700	270200	243800
15	267500	258700	231600	189000
16	267500	238600	193000	134400
17	267500	218800	154400	79600
18	200600	144400	77200	5200
19	133700	69600	0	69600
20	66800	5200	77200	144400
21	0	79600	154400	218800

Flux Distribution in Primary Core.—In order to determine the effect of the reluctance actually present in the iron core, and to estimate the error that is involved in neglecting it, we will select the instant when the phase angle of phase *A* is 30°, and will make use of the quantities and densities found in the preceding tables for that condition. This particular instant is chosen for study because at that time the greatest density of flux is found in a single tooth of the primary, and the total quantity of flux is a maximum. The values of flux given in the tables are not to be considered as final, but may be taken as first approximations, subject to later corrections should further study prove such corrections necessary.

At the instant chosen the flux is zero in tooth No. 7, and is most dense at teeth Nos. 1 and 13. In *Fig. 7* is given a drawing of the primary part of the magnetic circuit which includes half of teeth Nos. 1 and 13. From the fact

that the flux distribution in the primary teeth is symmetrical about tooth No. 7, it follows that, neglecting any local or leakage flux, the distribution in the primary core will also be symmetrical, or half the flux of tooth No. 1 goes to tooth No. 13; flux from tooth No. 2 goes to tooth No. 12; No. 3 to No. 11, and so on.

The probable path of the flux in each case is indicated by dotted lines in the figure. The position of these lines was determined by a method of trial and error. First the lines were sketched in as it was thought they should be drawn. Then equipotential lines were drawn crossing these at right-angles. Taking one section bounded by two equipotential lines, the flux of each path should occupy a width

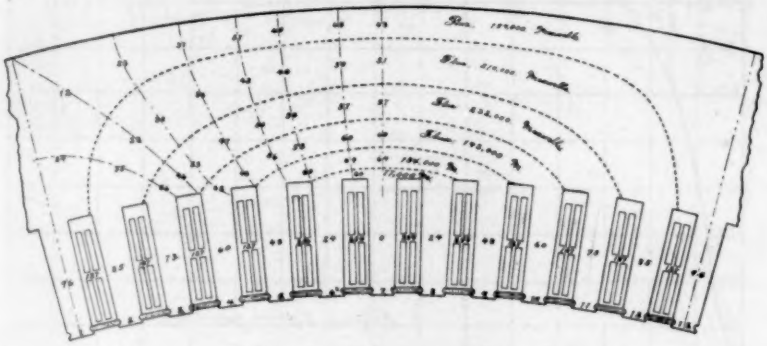


FIG. 7.

proportional to its amount and to the distance between the two equipotentials at that point. The new or corrected positions of the boundary lines of the flux paths were thus located, new equipotential lines sketched in, and a second computation made. This process was repeated until the corrections became negligible. The flux densities, in kilomaxwells per square inch, are marked on *Fig. 7* at a number of points.

The flux density and distribution in the primary core being thus determined with fair accuracy, a curve showing the relation between such densities and the M.M.F. per inch of path required to produce them was constructed. This curve (*Fig. 8*) was taken from a curve given by Parshall and

Hobart as the magnetization curve for laminations of "electric steel" of good average quality. Using this curve, careful determinations were made for the M.M.F.'s per inch of path, at equal intervals along each path in the core. The final average of these results is given below. In this and similar tables, path No. 1 means the path between teeth

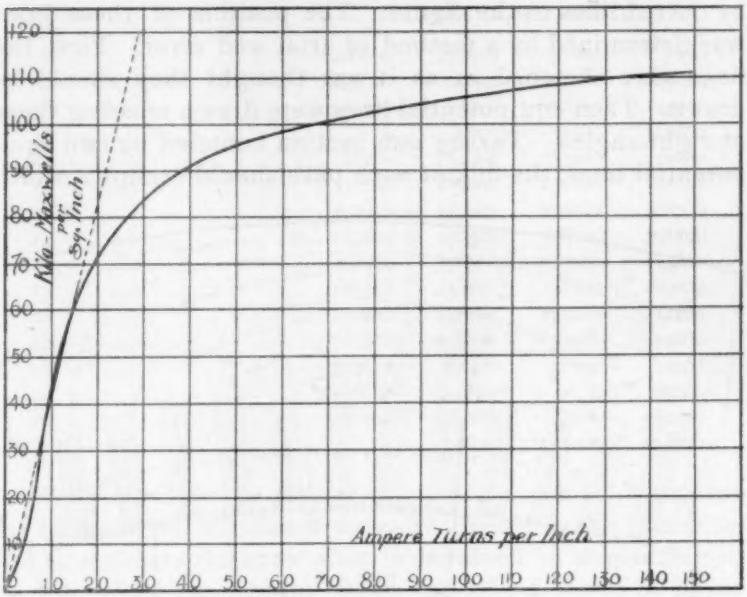


FIG. 8.

Nos. 1 and 13; path No. 2 is between teeth Nos. 2 and 12, etc.:

Path No.	Length in Inches.	Average Ampere Turns Per Inch.	Ampere Turns in Core.
1	13·3	9·1	121
2	10·35	9·9	102
3	7·25	10·8	78
4	5·1	11·6	59
5	3	12	36
6	2·5	10	25

The flux densities in the primary teeth are in general higher than in the core. The complete path in any case includes two teeth or a total lengh of 3·2 inches. The section of the tooth is not uniform, being smaller at the face

than at the root. Also considerable flux leaves the tooth before reaching the face, and takes a longer route through the air gap. One of these facts tends to counterbalance the other. It will be quite sufficiently accurate to make use of the average section and of the total length.

Again, making use of the curve in *Fig. 8*, the M.M.F. used up in the different teeth was determined, as follows:

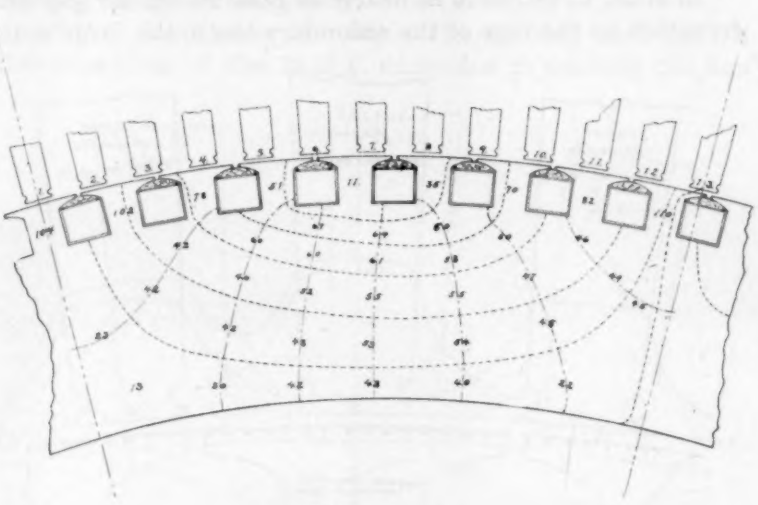


FIG. 9.

AMPERE TURNS USED UP IN PRIMARY TEETH.

Path No.	Average Ampere Turns Per Inch.	Ampere Turns in Teeth.
1	52	166
2	31	100
3	21	67
4	14	45
5	11	35
6	7	22

Flux Distribution in Secondary Iron.—In the discussion of the flux distribution of the primary, it was tacitly assumed that the question of secondary reluctance did not affect such distribution. This is not absolutely true, as an inspection of *Fig. 9* will indicate. In *Fig. 9* we have a drawing of the secondary part of the same magnetic circuit that was in part shown in *Fig. 7*. It may be

noted that the symmetrical distribution of the primary is not repeated in the secondary. This is, of course, due to the differing numbers of teeth in primary and secondary. This difference does not, however, have as much effect as might at first sight be supposed, since the tops of the secondary teeth nearly join, so that the secondary presents a nearly continuous magnetic surface.

In order to estimate as nearly as possible the air gap distribution to the tops of the secondary teeth, the large scale

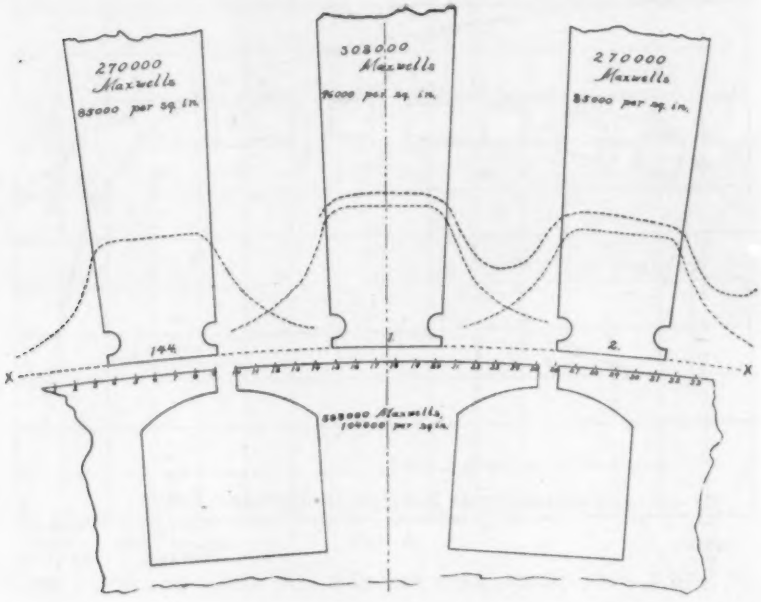


FIG. 10.

drawings of *Figs. 10* and *11* were constructed, and curves of flux density were made for each primary tooth of these figures. To determine these curves the method of Professor Goldsborough (Trans. Am. Inst. Elect. Engrs., 1898) was employed. The wavy dotted line in *Figs. 10* and *11* is the sum of the separate density curves, and indicates graphically the actual flux density over the surface of the secondary.

In estimating the quantity of flux entering a given sec-

ondary tooth from a particular primary tooth it was assumed that the primary tooth supplied that part of the total wave lying between two points of minimum flux on either side of the tooth. This area, and the part of the area lying over the secondary tooth in question, were measured, and the ratio of one to the other taken to be the ratio of the total flux through the primary tooth, to the part of it which entered the given secondary.

M.M.F. Used up in Air Gap.—The method used for the determination of the M.M.F. expended in sending the flux

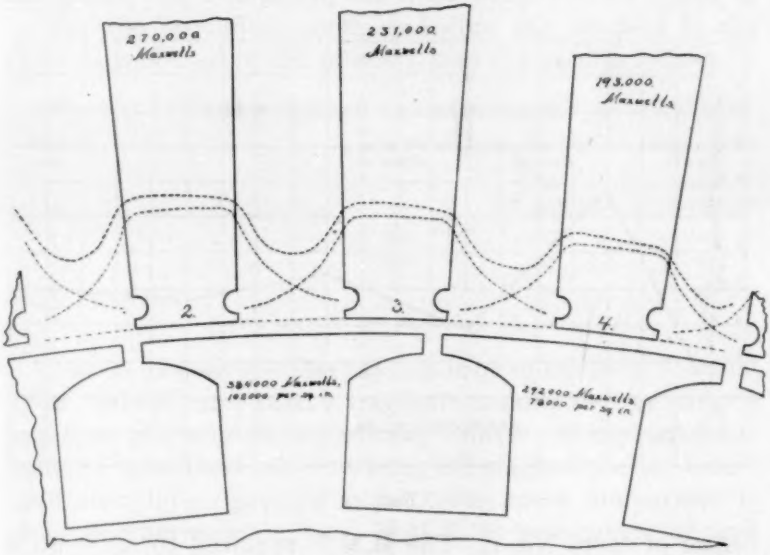


FIG. 11.

across the air gap depends upon the magnetic density curves of *Figs. 10* and *11*. The accuracy of this determination depends therefore upon the accuracy of those curves. The method may be illustrated by applying it to path No. 1. Taking the flux wave belonging to tooth No. 1, *Fig. 10*, the ratio of its maximum ordinate to its average ordinate is 1·23. That is to say, if there were no teeth or slots, and flux were distributed uniformly over the entire air gap at the average rate at which it occurs in the neighborhood

of tooth No. 1, the density would be less than the present maximum density in the ratio of 1· to 1·23.

The M.M.F. which would, in such an event, be necessary at the air gap is M.M.F. = ·045 × ·313 × 51,300· = 723 ampere turns. Where ·045 is the length of the air-gap, ·313 is the number of ampere turns required to set up one maxwell per square inch, through a distance of 1 inch in air, and 51,300 is the average density under tooth No. 1, and half of each of the adjacent slots.

Under the actual conditions we find a flux density of 51,300 × 1·23 = 63,200 maxwells per square inch under the

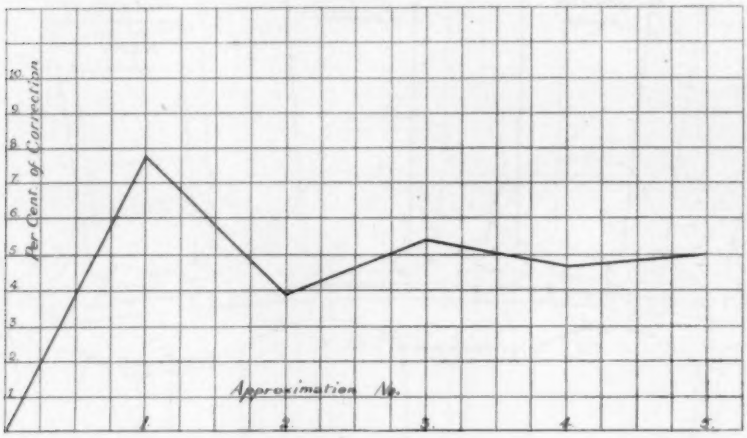


FIG. 12.

center of tooth No. 1. The M.M.F. required to set it up is M.M.F. = ·045 × 313 × 63,200 = 890 ampere turns. Considering all points within half an inch of the face of primary tooth No. 1 to be at the same magnetic potential, and all points on the face of a given secondary tooth to have a constant potential, it follows that the M.M.F. by any flux path across the air gap, from primary tooth No. 1 to the secondary tooth immediately under it, is 890 ampere turns. For the complete path No. 1, which crosses the air gap at teeth Nos. 1 and 13, the M.M.F. used up in the air is therefore twice 890, or 1780 ampere turns.

The same method applied to other portions of the air gap gives the M.M.F. needed for the other routes, as set down in the following table:

M.M.F. USED IN DOUBLE AIR GAP.

Path No.	Maximum Density in Air.	Ampere Turns for Double Air Gap.
1	63,000	1,780
2	55,500	1,560
3	47,500	1,340
4	40,000	1,130
5	31,700	890
6	15,900	450

For the secondary teeth and core the method is the same as was used in the primary, and the results follow.

M.M.F. USED IN SECONDARY IRON.

Path No.	Ampere Turns in Teeth.	Ampere Turns in Core.	Ampere Turns Total.
1	103	86	189
2	84	80	164
3	36	67	105
4	20	57	77
5	12	55	47
6	7	17	24

General Summary.—The final addition of the M.M.F.'s used up in various parts of the magnetic circuit, and for various paths, is given in the succeeding tables. A comparison is made in the second table between the magnetomotive forces used near the air gap and in the cores, and a comparison is also made between the total M.M.F. as now computed and the original estimate, which was made on the basis of 45 effective amperes per primary conductor:

TOTAL MAGNETOMOTIVE FORCE.

Path No.	A. T. in Cores.	A. T. in Teeth.	A. T. in Air Gap.	Total A. T.
1	186	269	1,780	2,235
2	172	186	1,560	1,918
3	151	103	1,340	1,594
4	126	65	1,130	1,321
5	83	47	890	1,020
6	43	26	450	519

COMPARISON.

Path No.	A. T. Cores.	A. T. in Teeth Plus Gap.	Total. A. T.	Previously Estimated.
1	186	2,049	2,235	2,032
2	172	1,746	1,918	1,778
3	151	1,443	1,594	1,524
4	126	1,195	1,321	1,270
5	83	937	1,020	1,016
6	43	476	519	508

The results of the computations are in remarkably close agreement with those which were estimated for a magnetizing current of 45 amperes, that being the best value that could be obtained from the test reports of a line of similar motors. It seems probable that the variation between different individual motors built from the same drawings would be as much as the difference between these results and the average of experiments.

Since no account has so far been taken of leakage or of the small amount of flux present in the slots, ventilating spaces, etc., the results of the computation show a slightly larger amount of flux in the iron, and therefore call for a larger magnetizing force than would be actually needed. A correction for this would bring the estimated and computed values into still closer agreement.

Effect of Correcting Certain Approximations.—The particular value of such a study as the preceding lies in the possibility that the results obtained may assist one in forming an idea of the reasonableness of certain customary approximations, and of the places where approximations may be freely used, and where only with great caution. We are now in a position to examine the effect upon the preceding study of various minor corrections. The propositions which have been assumed, tacitly or otherwise, are:

(1) All the reluctance of the magnetic circuits is contained in the teeth and air gap.

(2) All parts of the magnetic circuits have a constant permeability.

(3) No flux surrounds individual conductors, or conductor groups, locally.

(4) The flux is entirely confined to iron, except at the air gap.

(5) The conditions of the moment chosen are constant.

None of these statements are strictly true. It is desired to determine the probable error involved in taking them as accurate.

(1) From the accompanying table, it is seen that the reluctance of any magnetic circuit is principally that of the air gap and teeth. The per cent. of total reluctance found in that part of the circuit is as follows:

	Per Cent.
Path No. 1	92
Path No. 2	91·3
Path No. 3	90·7
Path No. 4	90·5
Path No. 5	91·7
Path No. 6	91.8
Average	91·3

The error in distribution, due to the inaccuracy of assumption No. 1, cannot therefore be greater than one due to a total change in the reluctance of about 10 per cent. As shown above, this change is practically the same by any path. The alteration in the *distribution* is therefore entirely negligible.

(2) The permeability of the air gap is of course constant. The permeability of the iron is nearly constant within a limited range, but is far from constant over a wider one.

Assumption No. 2 may be quite incorrect in some instances and negligible in others. In *Fig. 8*, a straight line is drawn through the origin in such a way as to become an average of the magnetization curve for a portion of its length. If the magnetization curve and the straight line coincided, it would mean that flux density in the iron was proportional to the magnetomotive force applied to it. For any given density, the error involved in assuming the above to be true, is indicated by the horizontal distance between the two curves. It may be noted that the two curves practically coincide between the flux densities of 25,000 and 65,000 maxwells per square inch.

In referring to *Figs. 7* and *9* it is seen that, with trifling exceptions, the flux densities in the primary and secondary cores lie within those limits. The primary and secondary teeth belonging to the three outer paths carry flux at a higher density than 65,000. The diminution in the actual flux carried by these three paths may be noted by a trial and error method, first applying a correction to the original value, then determining a correction for that result, and so on. The process is given in full for path No. 1, and the results are given for paths Nos. 2 and 3.

PATH No. 1.

FIRST APPROXIMATION.

Density in primary teeth	96,000
Ampere turns per inch for this density	52
Ampere turns as assumed (from straight line)	23
Difference per inch	29
Difference for path including two teeth	93
Density in secondary teeth	104,000 and 110,000
Average ampere turns per inch	115
Ampere turns as assumed	26
Difference per inch	89
Difference for path	80

Total loss in flux owing to decreased permeability of high-density teeth, equivalent to a loss in path No. 1 of 173 ampere turns, or 7·75 per cent. of the total.

SECOND APPROXIMATION.

Density in primary teeth (from preceding)	88,600
Density in secondary teeth " "	96,900 and 101,500
Ampere turns per inch, primary	36
Ampere turns per inch, as assumed	21
Difference per inch	15
Difference for path	48
Ampere turns per inch, secondary	66
Ampere turns as assumed	24
Difference per inch	42
Difference for path	38

Total loss in flux equivalent to a loss of 86 ampere turns, or 3·9 per cent. of the total.

THIRD APPROXIMATION.

Density in primary teeth (from preceding)	92,300
Density in secondary teeth " "	100,000 and 105,000
Ampere turns per inch, primary	444

Ampere turns per inch, as assumed	23
Difference per inch	21
Difference for path	67
Ampere turns per inch, secondary	85
Ampere turns, as assumed	25
Difference per inch	60
Difference for path	54

Total loss in flux, equivalent to a loss of 5·4 per cent. of the total, or to 121 ampere turns.

FOURTH APPROXIMATION.

Density in primary teeth (from preceding)	91,000
Density in secondary teeth	98,300 and 104,000
Ampere turns per inch, primary	40
Ampere turns per inch, as assumed	22
Difference per inch	18
Difference for path	58
Ampere turns per inch, secondary	75
Ampere turns, as assumed	25
Difference per inch	50
Difference for path	45

Total loss in flux, equivalent to a loss of 4·6 per cent. of the total, or to 103 ampere turns.

FIFTH APPROXIMATION.

Density in primary teeth (from preceding)	91,500
Density in secondary teeth	99,000 and 105,000
Ampere turns per inch, primary	41
Ampere turns, as assumed	22
Difference per inch	19
Difference for path	61
Ampere turns per inch, secondary	80
Ampere turns, as assumed	25
Difference per inch	55
Difference for path	50

Total loss in flux, equivalent to a loss of 5 per cent. of the total, or 111 ampere turns.

So many as five approximations are not necessary, except for illustration. The final value may usually be predicted closely enough after two or three approximations. The manner in which the final value is approached is indicated graphically in *Fig. 13*. The change due to each successive approximation is seen to be about half of the preceding change.

The immediate effect therefore of the low permeability of the high density teeth is to reduce the flux about as fol-

lows, the values for paths Nos. 2 and 3 being obtained as above:

	Per Cent.
Path No. 1	5
Path No. 2	4
Path No. 3	1

Such a change in the flux of these teeth would cause other slight changes which in turn would react upon these values, some increasing and some diminishing them. Except as hereinafter noted, variations of that character are negligible.

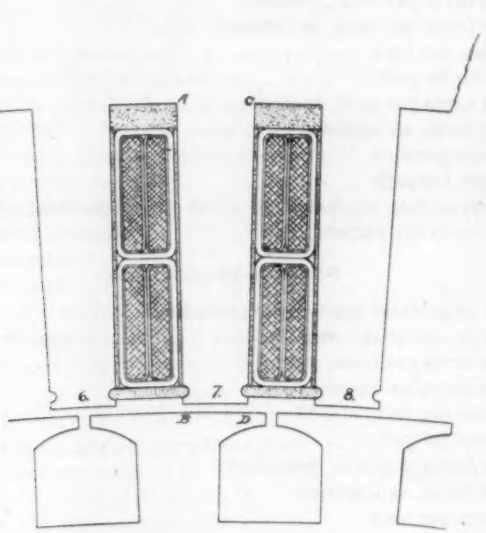


FIG. 13.

(3) *Leakage Flux.*—Under the specified conditions, *i. e.*, with the secondary on open circuit, the flux surrounding conductors locally, or surrounding groups of primary conductors, without entering the secondary, is an extremely small per cent. of the total amount. Under other conditions, however, such flux may become important, and it is desirable that its amount and distribution, with varying primary currents, should be carefully studied. The flux conditions that have heretofore been chosen for discussion are those when the phase angle of current in phase *A* is

30°. The currents in the slots of *Fig. 7* are there indicated, the larger currents being found in the central slots. Referring to *Fig. 13*, we find an enlarged drawing of teeth Nos. 6, 7 and 8, with the conductors lying between them.

Leakage flux may be divided into two parts.

(*a*) Complete flux path in non-magnetic media.

(*b*) Flux path partly in iron.

Flux as in (*a*) occurs along the total length of each primary conductor, and along the end connections as well. Flux as in (*b*) is found only for a conductor length equal to the net length of laminations parallel to the shaft.

To obtain a rough idea of the order of magnitude of class (*a*), neglecting end connections, we will assume flux paths coincident with insulation sheaths, as indicated in *Fig. 13*. A computation on this basis gives the following results:

Total flux per slot surrounding a single conductor only .	64 maxwells
Total flux per slot surrounding a pair of conductors . .	134 "
Total flux per slot surrounding all four conductors . .	165 "
Total flux in insulation surrounding any single conductor of *Fig. 13*	248 "

These figures are not given as at all accurate, since the assumption on which they are based is a very rough one, but they serve to show that the leakage flux which occurs entirely in non-magnetic paths is quite unimportant as compared with the total.

Leakage Flux Partly in Iron.—This is a very complex matter, and one which is difficult of analysis. Obviously, so far as affects the primary alone—and we have as yet only considered primary E.M.F.'s—there will be no leakage flux unless a given tooth carries flux at the same time in two directions. Fsr example, in *Fig. 13*, with the conditions of the moment, and no leakage, flux travels downward through tooth No. 6, and upward through tooth No. 8; no flux existing in tooth No. 7.

With leakage, flux would travel downward in tooth No. 6, and upward partly in tooth No. 7, and partly in tooth No. 8, while some flux traveling upward in tooth No. 8 would return downward through tooth No. 7, completing a

circuit without reaching tooth No. 6. That is, flux would be traveling upward on the left-hand side of tooth No. 7, and downward on its right-hand side. Such a flux would be most dense along either edge of this tooth, and would be set up by the difference between that part of the M.M.F. of the currents in slot 6–7 acting between the points *A* and *B*, *Fig. 13*, and the part of the M.M.F. of the currents in slot 7–8 acting between the same points.

From symmetry, neglecting any non-symmetry of the secondary, the M.M.F. 6–7, between *A* and *B* is equal to the M.M.F. 7–8 between *C* and *D*. The M.M.F. of 7–8 between *A* and *B* is less than this by the amount used up in forcing flux from *C* to *A* and from *B* to *D* through the iron, or by a trifling amount. This trifling difference acting along the tooth from *A* to *B* and across the air-gap at *B* would indeed set up a very slight flux, but not enough to be worth considering.

Leakage that may occur with respect to the secondary conductors, *i. e.*, that which may circle primary conductors, and not those of the secondary, is of more importance. Such flux may be set up along the ends of the primary teeth and across the intervening slots; or across the tops of the secondary teeth and between the ends of the secondary projections, or along the air gap. The amount of this leakage might be obtained if it were possible to compute the reluctance of the combined path and the M.M.F. applied to it. In so far as we may approximate to such determinations we may approximate to a determination of the leakage between primary and secondary.

For present purposes, with secondary conductors carrying no current, the M.M.F.'s are not large, and the distances through air are large, so that this flux is not very important. The matter of leakage with the motor running normally will be discussed later, though no very satisfactory method for predetermining this quantity seems to be possible, at least without an amount of labor disproportionate to the probable results.

(4) *Effect of Flux in the Slots.*—The amount of flux that crosses through the nonmagnetic substances lying in a slot

depends principally upon the degree to which the iron of the neighboring teeth is saturated. In the case of the present motor the teeth densities are rather moderate and a very small proportion of the flux crosses through any slot. For illustration we will compute the probable flux found on either side of primary tooth No. 1 and present in the ventilating and lamination spaces. We have:

Ampere turns per inch in tooth No. 1	52	
Ampere turns per inch through slot therefore are not more than	52	
Maxwells per square inch in slot not more than	166	
Area for flux in slot	3·78	sq. in.
Area for flux in ventilation spaces, etc.	·73	"
Total area	4·51	"
Total flux, maxwells	750	
Flux in tooth No. 1	308,000	
Proportion of flux in neighborhood of tooth No. 1, but not in iron	·24	p. c.

This is the worst case for the primary. In the secondary the maximum tooth density was estimated at 110,000 maxwells per square inch. Making a similar computation for this case we find the following:

Ampere turns per inch	140	
Corresponding flux density in air	450	
Total area for this density	6·67	sq. in.
Total flux not in tooth	3,000	
Proportion of flux in neighborhood of tooth but not in iron	·96	p. c.

(5) *Conditions of the Moment.*—At the moment chosen for investigation the flux per pole has the greatest possible value and the flux in a single tooth at the center of a pole is at maximum density. The approximations that have been made are therefore less close than at any other moment.

The only other item which may change is the position of the secondary structure. Since the primary and secondary are unsymmetrical and the number of secondary teeth is not a multiple of the number of poles, it follows that the conditions of the moment, as studied in *Figs.* 7 and 9, are not precisely those of any other magnetic circuit, even at this instant. The changes which may be produced by a shifting of the secondary are changes in secondary-tooth density.

The conditions of *Figs. 7* and *9* probably represent a fair average, since they are favorable to a low density in the teeth at the left of the figures and to a high density in those at the right, both being for the same magnetic circuit.

Operation.—So far nothing has been said about the theory of the motor or of the principles of its operation. We have simply examined the behavior of the magnetic circuit of a particular machine when an appropriate polyphase E.M.F. was applied to it. It remains to note qualitatively the behavior of this motor when running, and then to discuss the performance of induction motors in general.

[*To be continued.*]

MONEY SAVED BY UNITED STATES GEOLOGICAL SURVEY MAP.

In its issue of May 21, 1903, the *Engineering News* has an interesting article on the very expensive construction of the Pittsburg, Carnegie and Western Railroad near Jewett, Ohio, in which the following paragraph occurs:

"Perhaps the most instructive location problem solved in this work was one involving the use of an atlas sheet of the United States Geological Survey with a contour interval of 20 feet. Before the issue of this particular atlas sheet the preliminary surveys and first location of the proposed line had been completed, and work was about to begin when a new resident engineer, Mr. T. H. Loomis, was appointed. Happening to be personally acquainted with the Government topographer, Mr. W. T. Griswold, who was then engaged in mapping this part of Ohio, Mr. Loomis secured from him a photograph of the contour map then almost finished. From this photographic copy Mr. Loomis projected a new location between stations 650 and 836, effecting thereby a saving of 2,200 feet in distance and 75° of curvature, besides eliminating 600 feet of tunnel. This change measured in dollars and cents resulted in reducing the first cost of that portion of the road by at least $85,000. Turning to the last annual report of Mr. Charles D. Wolcott, Director United States Geological Survey, we find that 1864 square miles of the State of Ohio have been mapped thus far, at a cost of $12,000; yet one small atlas sheet, covering some 220 square miles, has been the means of saving a sum more than seven times what it has cost to map the whole 1864 square miles. As a tribute to the accuracy of the Government topographer, Mr. Griswold, it may be well to add that when the railway engineers ran their profile levels along the paper-projected line, at no place did the actual elevation differ more than 16 feet from the elevation scaled off the contour map. To any engineer acquainted with the roughness of Eastern Ohio and with the approximate methods necessarily employed in Government topographical surveys of such vast areas, these figures speak forciby enough. And it is well that just such facts as these should become generally known, for there has been altogether too great an apathy in the past in furthering the work of the United States Geological Survey—a work that is destined to be of incalculable value to every citizen of the United States."

The Otis Elevator Company's Electric Elevator for Private Residences.

[*Being the Report of the Committee on Science and the Arts. Sub-Committee: T. C. Smith, Chairman; Francis Head, J. Logan Fitts, C. C. Heyl.*]

HALL OF THE FRANKLIN INSTITUTE,
[No. 2221.] PHILADELPHIA, June 1, 1902.

The Franklin Institute of the State of Pennsylvania for the Promotion of the Mechanic Arts, acting through its Committee on Science and the Arts, investigating the merits of the Otis Elevator Company's Electric Elevator for Private Residences, reports as follows:

This elevator is the subject of numerous patents, covering a long period of time, and which are interesting as showing the gradual growth and development of this apparatus through its various stages, each step having been made as the necessity for it arose.

When elevators are to be used in public buildings and where the traffic is of such amount as to warrant the placing of an attendant in charge of each machine, the question is comparatively a simple one, as a great deal can be left to the discretion of the operator and many operations can be performed or omitted at his judgment. In the case of a machine, however, intended to be operated by persons absolutely unskilled in the art, and with no one near at hand to rectify mistakes, it becomes a serious and complicated problem to provide means to meet and fill the requirements of the many different combinations that may arise. This has been admirably carried out in the apparatus under investigation.

The investigating committee had an interview with Mr. Ihlder, of the Otis Company, the inventor of many of the devices covered by the later patents, and received from him a full explanation of the working of the apparatus. They then examined one of these machines in operation in this

city, going carefully over the apparatus itself and testing the operation of the car in all combinations which they could think of as likely to occur in practice. The particular apparatus examined was one in which direct current at 220 volts is supplied from the Edison Central Station both for operating the motor and working the controlling apparatus; but the Otis Company presented wiring diagrams, showing the arrangements made for operating the motive-power with

500 volts direct current, using a primary-battery circuit for operating the controlling mechanism, and diagrams for operating the motor-power with alternating current of high or low tension, but using primary-battery circuits or derived circuits for operating the controlling mechanism, the general principle being the same in all.

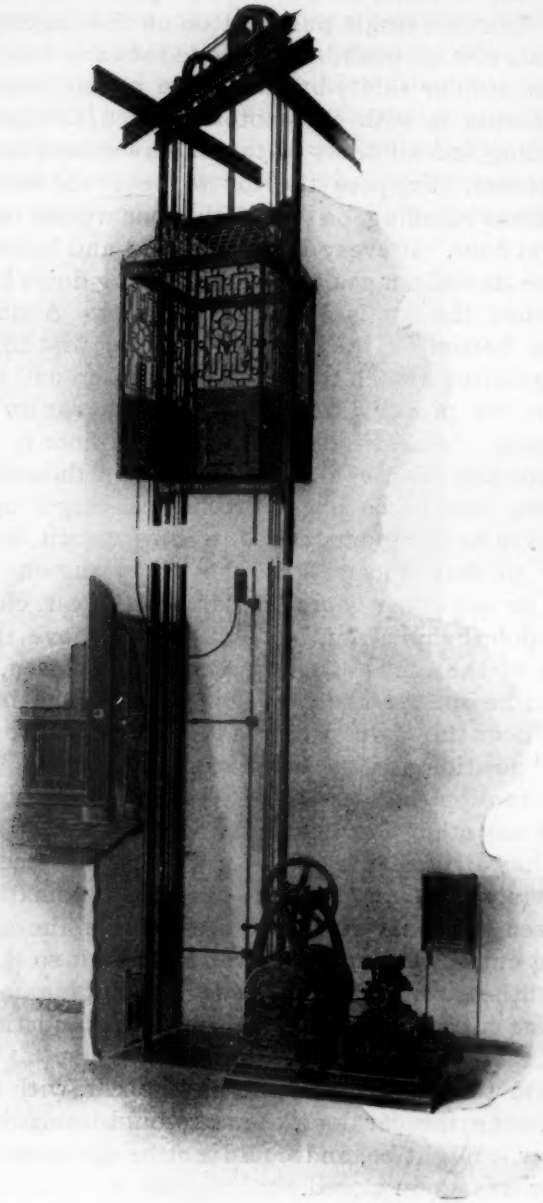
The operation of the particular apparatus examined was as follows:

The elevator hatchway is provided with a door on each

floor and the elevator car itself is also provided with a door. On each floor is a single push-button on the landing, and in the car is a row of push-buttons, one for each floor and one additional stop or safety-button. The normal condition of the apparatus is with the motor stopped, the car at some floor-landing and all doors of the hatchway and the door of the car closed. Suppose the car to be at the second floor and a person standing on the fifth floor wishes to descend to the first floor. If every door is not shut and locked the car cannot be started nor can any of the landing-doors be opened except when the car is opposite that floor. A single push upon the button on the fifth-floor landing first throws the main regulating switch to the "up" position and starts the motor in the proper direction to bring the car up from the second floor. When it arrives at the fifth floor it automatically stops and releases the lock upon the fifth-landing door, permitting this to be opened. The passenger opens this door, and in so doing cuts the controlling circuit, leaving the elevator so that it cannot be moved by any one pressing buttons on any other floor. He enters the car, closing the landing-door behind him, but still cannot move the car as the door of the car is open. When this is closed, and only then, can he operate the car. On pushing the button for the first floor the main switch is immediately thrown to the "down" position and the car starts downwards. While the car is in motion the pressing of a button on any of the other floors or any other floor button in the car has no effect until the car has arrived at the floor for which it has been started. On arriving at the first floor the car stops automatically, and the passenger would first open the door of the car and by so doing cut out the main controlling circuit so that no one can start the car until he has opened the landing door, passed out of the car and closed both the car door and the landing door.

Should the passenger while in the car, with the car in motion, open the car door, the car would immediately stop wherever it might be, and could not be again started until the door was again closed.

It is evident that if at the moment of the car arriving at its destined floor, and before the car door had been opened,



some one should press a landing-button to call to some other floor, it would immediately start for that floor. It is to provide against this contingency that the safety or stop-button is provided in the car. Pressing this button stops the car at once, wherever it may be, and places the control of the car again in the hands of the passenger. Another function of this stop-button is as follows:

Should the passenger, starting downwards (say from the fifth floor to the first), and after passing the third floor, change his mind and wish to return to the fourth floor, it will be seen from what has been said already, that pushing the fourth-floor button will have no effect. Pushing the stop button, however, stops the car and sets the various devices in such position that pressing the fourth-floor button will now send the car back to that floor without waiting for the car to descend to the first floor and make a fresh start from there.

A number of additional variations to meet special requirements were also shown, such as a provision that required the button in the car to be kept pressed down in order to keep the car moving. In such case, if the button is released, the car immediately stops. A signal bell is also provided to give an alarm, if from any reason the car should stop while a passenger is in it, and between floors.

The apparatus, as examined by the committee, seemed to be of the most thorough and substantial kind, with a notable absence of the delicate or flimsy construction so often associated with electrical devices. The contacts especially seemed ample and strong and fully able to stand the wear and tear of everyday unskilled operation.

For the ingenuity displayed in meeting the various combinations of an exacting service, and for the thorough and mechanical manner in which this apparatus has been developed so as to place it in the hands of the public upon a commercial basis, the Franklin Institute recommends the award of the John Scott Legacy Medal and Premium to the inventors.

Adopted Wednesday, October 1, 1902, and certified to be a correct copy from the committee's records.

WM. H. WAHL, *Secretary.*

CHEMICAL ANALYSIS OF IGNEOUS ROCKS.

The Geological Survey is about to publish a work of exceptional importance to students of igneous rocks and to geologists who have an interest in these objects. It is entitled "Chemical Analysis of Igneous Rocks Published from 1884 to 1900, with a Critical Discussion of the Character and Use of Analyses," by Henry Stephens Washington, and it will appear as No. 14 of the series of Professional Papers.

As its title indicates, it is a collection of all chemical analyses of igneous rocks published within a period of sixteen years, going back to the time of the last compilation of the kind by Justus Roth, a German geologist. All igneous rocks are products of the consolidation of liquid or molten magma. They are sometimes glassy, sometimes partly crystalline, and sometimes entirely so. It is evident from observation that any particular magma which has been erupted from the depths of the earth, through fissures, to the surface, where it issued in lava streams, has consolidated in different places with many different textures; and it is also known of many magmas that the resulting rocks may have different mineral composition, when fully crystalline, according to the influence of environment upon the cooling masses. The chemical composition is, therefore, the most fundamental or constant character of all these products from the eruption of any magma.

The tables of Dr. Washington give nearly 3,000 analyses of rocks from all countries in the world. It is interesting to note that by far the largest number, and also the best ones, are from the United States. The author lays so much weight on the character of the analyses that he separates the good from the bad on certain principles, and publishes them in two parts. The good analyses, some 1,600 in number, are arranged by kinds of rock, classed according to the recently published quantitative classification of igneous rocks by Cross, Iddings, Pirsson and Washington. The reason for using this new system is that the old rock names mean so little in regard to this fundamental feature of chemical composition that the analyses cannot be grouped in the most useful manner under those heads. The new classification, being based on chemical composition very largely, is suited to bringing analyses of similar rocks together. Certainly, the examination of the tables of good analyses shows that rocks which have practically the same chemical composition have been called by a great many different names under the old style of classification; and, of course, the converse is true, that the analyses of any rock family under the old classification are distributed among a good many divisions of the system adopted. The analyses which are too poor to enable anyone to classify the rocks according to the new system are grouped in the second part, under the old names. By means of double and complete indexes, however, the author facilitates reference to all analyses of any of the older systematic rock groups, such as granite or syenite. The geographic index refers to all rocks of certain regions.

An interesting discussion of the value of accurate analyses of rocks to the science of petrography precedes the tables, and reviews the means of judging as to the quality of an analysis. The author enters an effective plea for careful investigation in this direction.

The Acker Process for Alkali and Bleaching Powder by the Electrolysis of Fused Common Salt.

[*Being the Report of the Committee on Science and the Arts. Sub-Committee: C. J. Reed, Chairman; H. F. Keller, Samuel P. Sadtler, Carl Hering, Joseph W. Richards.*]

HALL OF THE FRANKLIN INSTITUTE,
[No. 2242.] PHILADELPHIA, May 1, 1903.

The Franklin Institute of the State of Pennsylvania for the Promotion of the Mechanic Arts, acting through its Committee on Science and the Arts, investigating the merits of the Apparatus and Process of Charles E. Acker, for Manufacturing Caustic Alkali and Bleaching Powder by the Electrolysis of Fused Common Salt, reports as follows:

The process and apparatus are the subject of United States Patents 649,565, 674,691 and 687,709, of May 15, 1900, and May 21 and December 3, 1901, respectively.

The early experiments with the process, as well as the description of its present installation, are set forth very fully by Mr. Acker himself in an illustrated article in the *Transactions of the American Electrochemical Society*, Volume I, 1902; further details may also be found in an article written by the chairman of this committee in the journal *Electrochemical Industry*, October, 1902, p. 54. In addition to this, Mr. Acker has written letters containing further details for the information of this committee, has given copies of works—analyses of his raw materials and products, and has sent large samples of the same to three members of the committee. Most of the members of the committee have conversed with Mr. Acker, and three members have thoroughly inspected his plant in operation at Niagara Falls.

It is unnecessary in this report to rehearse the already published details of the process and its operation. From actual inspection of the plant the committee is satisfied that the published information referred to is substantially

correct. The actual operation of the plant is on such a scale as to leave no doubt as to its commercial practicability. From the facts submitted to the committee, it appears that the business can be operated profitably at present market values of the products and at the cost of power at Niagara Falls.

The various parts of the plant are well systematized and arranged. The mechanical appliances around the furnace and for handling and storing the various products are well worked out, and reflect credit on the company's engineers.

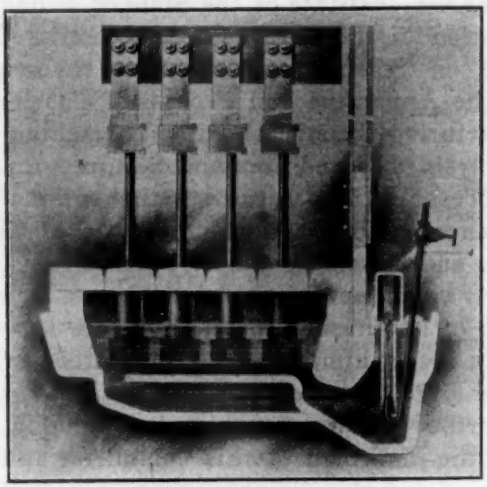


FIG. 1.

The electrolytic part of the plant is installed in a creditable manner, the avoidance of chlorine gas in the pot-room, by the use of powerful suction, being complete. The process itself attracts attention by its directness, the salt being decomposed in one room, the caustic produced passed through a window into the next, and there the settled caustic ladled into drums and sealed ready for shipment, all within a distance of perhaps thirty feet, and in two operations.

As compared with the wet electrolytic processes, the advantages of this system of working are: (1) its directness; (2) the very heavy current sent through each pot (as much

through one Acker pot as through fifteen Castner cells); (3) the absence of the evaporation of caustic and boiling down to dryness; (4) the absence of water solutions, requir-

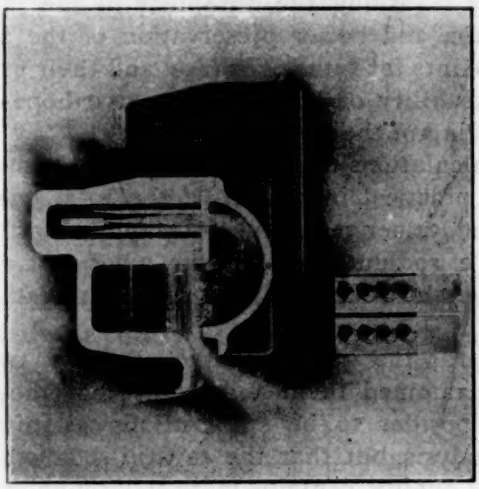


FIG. 2.

ing special pumps and a complicated circulating system; (5) the absence of the use of mercury. The disadvantages of this system are: (1) a larger power requirement—6·75 volts in place of 4·5, or some 50 per cent. more; (2) the rapid

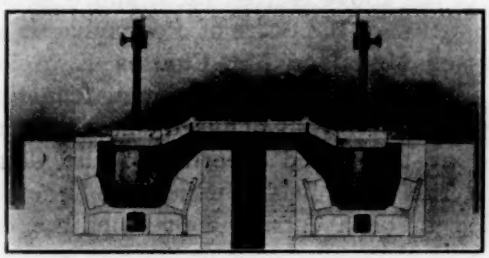


FIG. 3.

destruction of the apparatus; (3) the rapid destruction of the anodes; (4) the more arduous work of the pot-men.

The committee wishes to commend the perseverance

with which the Messrs. Acker have worked at their experiments and finally brought them, as it were by main force of pluck and determination, to a commercial standing. There are still improvements possible in the working of the plant, particularly regarding the durability of the pots and the simplification and better preservation of the anodes; but these are points for future advance, and their presence and evident capability of improvement give hopes for a still better working of the process.

Some calculations made by the committee may be of scientific and practical interest: Of the total energy of the current used, 54 per cent. is usefully applied to the chemical separation of sodium from chlorine, 9 per cent. is utilized in melting the salt used, and 37 per cent. is radiated from the apparatus.

As regards the quality of the products, two chemical members examined them and report that they found the bleaching powder to be substantially as given by Mr. Acker's analysis, but that the caustic soda, while of good commercial quality, contains more sodium chloride and carbonate and less caustic soda than Mr. Acker's analysis shows. In view of this, the recommendation is made to Mr. Acker that more care should be exercised to prevent the carbonation, and particularly the entrance of sodium chloride accidentally into the fused caustic, during its collection in the pot-room.

In view of the above recited facts and observations, the Franklin Institute of the State of Pennsylvania awards the Elliott Cresson Medal to Mr. Charles E. Acker, for his apparatus for and process of producing caustic soda and chlorine by the electrolysis of fused common salt.

Adopted at the stated meeting of the Committee on Science and the Arts, held Wednesday, December 3, 1902, and certified to be a correct copy from the committee's records.

WM. H. WAHL, *Secretary.*

The Goldschmidt Theory of Harmony.

[*Being the Report of the Committee on Science and the Arts, with Appendix. Sub Committee: Jos. W. Richards, G. A. Hoadley, A. S. Mackenzie, E. Goldsmith, C. C. Heyl, J. F. Walls.*]

HALL OF THE FRANKLIN INSTITUTE,
[No. 2222.] PHILADELPHIA, November 1, 1902.

Dr. Victor Goldschmidt's "Harmonie und Complication" sets forth a new view of musical harmony which your committee has been asked to pass upon. In reality, the treatise referred to is the announcement of a new law governing the development of our perception of harmonies in colors, proportions and taste, as well as the harmonies of sound.

The author takes up the subject as a crystallographer. He has made a particular study of the relations to each other of the planes upon the surfaces of crystals, particularly of those series of planes which lie extended or developed in zones between two primary or reference planes. By the method of gnomonic projection, the reference planes and the planes between them are represented by points on a straight line. The author's theory that the crystallizing forces building the primary planes unite in simple multiples to produce resultant forces which build the intermediate planes, is so well proven and so clearly explains the facts that it has been generally accepted as the correct explanation of the genesis of crystal forms, and the modern nomenclature of crystal form (Miller's) is being interpreted and taught in the light of this theory. The author's contributions to practical and theoretical crystallography have been of the highest value in the modern development of that branch of science, and have placed his name in the front rank of modern crystallographers.

The "law of complication," as applied to crystal faces, is simply a statement of the fact that if the forces which build the primary pinacoids or primary planes of a zone are taken as the original crystallizing forces, their combination

in simple numerical proportions (as would be, in fact, indicated by Miller's indices), produce resultant forces, which are respectively the builders of the other planes in the zone. The truth of the theory is seen in the striking manner in which all the important laws of crystallography may be derived from it as corollaries. Its truth implies as one corollary that Miller's indices for crystal planes will all be simple whole numbers, since they really represent the proportions in which the primary crystallizing forces unite to produce any plane. This change in the point of view of regarding or interpreting Miller's symbols is a magnificent advance in practical crystallography, and has facilitated very greatly the obtaining of correct fundamental ideas on crystal genesis, particularly on the part of students. Another corollary is the law of the simple mathematic ratio, which postulates the simple numerical relations existing between the relative distances cut off on the axes of reference by different planes, or their simple numerical relation to the arbitrarily chosen fundamental intercepts of the fundamental pyramidal plane. Still another corollary is the zone equation, or the equation of condition governing the relation to each other of the intercepts of planes which lie in one zone. Another deduction is the harmonic ratios existing between the intercepts, on the same axis, of all planes lying in a zone. In short, all of the important laws and generalizations which have been so far made in crystallography are found to be necessary deductions from the theory of the genesis of planes according to the "law of complication" as put forward by Dr. Goldschmidt.

The fact of the "harmonic ratio" existing between the intercepts of planes on one axis led Goldschmidt to the query as to whether the distribution of the notes in our harmonic scale might not be governed by the same kind of a law of complication which appears to govern the distribution of the planes in the zone. To test this question, Goldschmidt applied his crystallographic nomenclature to the notes of the ordinary octave. He said, let *c*, whose relative number of vibrations we take as 1, represent one of our primary crystal planes, with a symbol of *o*; let upper $\bar{c}$, with

vibrations equal to 2, represent the other primary plane, with the symbol ∞ (infinity); then let us give the appropriate and necessary symbols to the intermediate notes, which is easily done by taking for each its relative number of vibrations and dividing its distance from 1 by its distance from 2. The octave being thus transformed into a zone, stretching between *c* equals *o* and $\bar{c}$ equals ∞, the intermediate notes, with the exception of *d* and *b*, are found to correspond with the ordinary development of a zone in a crystal. If a similar zone is stretched from *g* (3/2) to upper $\bar{g}$ (6/2), a similar zonal development is observable, with $\bar{d}$ and *b* important members of this series. The conclusion is then deducible that our octave consists of two real harmonic series superposed on each other, one between *c* and $\bar{c}$, the other between *g* and $\bar{g}$.

The next deduction from this observation is, that only those notes can form an agreeable chord which belong to one series, and that, therefore, musical chords can be likened to crystal zones, in which the possible occurrence of all harmonious parts is governed in both cases by the law of complication.

Our author elaborates this thesis at length, and whether his method of regarding the genesis of a chord is in reality correct or not, there is no denying the fact that his conception does apply to the understanding or explanation of musical chords as we know them.

Regarding the succession of chords in a sequence, the ground tones on which the successive chords are built are to be considered. The ground tone is that note in any chord which must be regarded as *o* in the crystallographic nomenclature, and between which and its octave, ∞, the zone or harmonic series is developed according to the law of complication. If the ground tones of successive chords are thus regarded, it is found that there is no arbitrary or accidental succession of ground tones, but that they all belong, in one line or musical unit, to one succession or zone of notes, which are related among themselves by the same law of development or complication. This gives a running chord as the law of sequence for the ground tones, and no

ground tone may be introduced foreign to that zone or set of related notes. Thus we obtain a chord of succession for the ground tones, which itself has a ground tone. Other parts of a composition may have other ground tones for the chords which govern the succession of its minor ground tones; but all these ground tones of the third order, if we may so call them, are again related to each other by the law of complication, and thus furnish a ground tone for the whole composition.

To thoroughly understand the reasoning of Dr. Goldschmidt is not easy. Your sub-committee have met several times and discussed the subject at length among themselves, and have persevered in the endeavor to follow and understand the author's thought and method. It is quite clear, for instance, to all the committee that the application of Goldschmidt's method to simple melodies, such as "Gaudeamus Igitur," explains most clearly and undeniably the musical structure and composition of the piece. The proof here is convincing that the method of interpretation is sound and of utility in helping to grasp the nature of the composition, and see into its musical structure. Further on, the author analyzes one of the most difficult of compositions, Palestrina's "Stabat Mater Dolorosa," a composition which the great Helmholtz designated in his "Lehrbuch der Tonempfindungen," as "a mass of notes thrown together in the most promiscuous manner, violating every modern rule of harmony, and yet a composition of undeniable musical power," and further remarked that "the master key which would enable us to unlock the tangled threads and understand the musical structure of the piece has yet to be found." Analyzing this *crux experimentis* by the same rules of the law of complication, Goldschmidt arrives at a graphic and striking exposition of harmonious structure and development in this composition, which is quite as plain as his analysis of the "Gaudeamus Igitur." The proof is convincing that the key to the harmonies of this masterpiece has been found; the master key, whose absence Helmholtz regretted, has unlocked the secrets of its musical structure.

Just at this point, however, your committee are not unanimous. We all admit that Goldschmidt has discovered *a key*, but the member most competent to speak as a musician cannot admit the necessary conclusion from Goldschmidt's analysis, that the piece is based on the ground tone *A* flat. His modern musical training prevents him from seeing the possibility of that conclusion being correct, yet he admits that if he studied out more at length the different modes prevalent in Palestrina's time, the conclusion may not be impossible; yet it is unexplainable in our modern way of interpreting keys.

The majority of your committee feel, however, that the proof that Goldschmidt's method of analysis and explanation is correct is so abundantly shown by his analysis and demonstration of musical symmetry and harmonious structure in that hitherto unexplained masterpiece—the "Stabat Mater" of Palestrina—that they cannot but regard the divergence of Goldschmidt's conclusion, as to the fundamental ground tone of the piece, from that which modern musical theory ascribes to it, as being due to the discrepancies of the latter; for a theory which was admittedly unable to explain the structure of the composition has no grounds for refuting the necessary conclusions of a theory which does explain, in a most striking manner, all the intricacies of the composition.

The verdict of your sub-committee is that so purely original and scientifically important a work deserves the highest recognition which is in the power of the Institute, and therefore recommend that "The Elliott Cresson Gold Medal" be awarded to Dr. Victor Goldschmidt, of Heidelberg, for his contributions to the science of music, as embodied in his work, "Ueber Harmonie und Complication."

As an appendix to this report, we present a simplified presentation of the theory elaborated by Dr. Goldschmidt, written by the chairman of your sub-committee, which will explain to the general scientific public the ideas and conclusions of the work examined.

Certified as a correct copy from the committee's report.

WILLIAM H. WAHL, *Secretary.*

APPENDIX.

The Goldschmidt Theory of Harmony.

By Joseph W. Richards, Ph.D.

(*Read at the meeting of the Physical Section of the Institute, January 22, 1902.*)

Dr. Victor Goldschmidt is professor at the University of Heidelberg, and one of the best-known crystallographers in Europe. His "Index of Crystal Forms" and his "Angle Tables" are monuments of industry and research; he is a frequent contributor to Groth's *Zeitschrift für Krystallographie und Mineralogie.* His development of the methods of gnomonic projection, and of the application of the "two-circle" or "theodolite" goniometer to crystal measurements, has made his unpretentious laboratory, of but three small rooms, the Mecca of numerous American students of crystallography.

Less than a year ago, the genial professor surprised his friends no less than the scientific public by publishing an octavo book of 136 pages* on the subject of musical harmony, and the application to it of the law of inter-relation which governs the distribution of planes in zones on the surfaces of crystals. This law was discovered by Goldschmidt in his crystallographic studies, and is called by him "Das Gesetz der Complication," which we may translate rather freely as "The Law of Inter-relation." This law is the most general law of crystallography; it explains the distribution of all possible planes between two primary planes. It is so fundamental that it includes as corollaries the formerly recognized fundamental laws of crystallography, viz., the law of the rationality of the indices, the law of zones, and the law of constancy of the angles. But not only is this law the primary law of crystallography: Goldschmidt believes he has proved that the same fundamental law governs, in musical harmony, the harmony of notes in a chord, the sequence of related notes, and the rela-

* "Ueber Harmonie und Complication." Springer, Berlin, 1901.

tions between a sequence of chords. In fact, "Das Gesetz der Complication" is also the fundamental law of musical harmony.

Further than this, although foreign to our present subject, an application can be made of the same law in discussing the harmonies of colors, the historical development or evolution of the color sense, and also to the æsthetic sense of proportions. Goldschmidt makes some very suggestive inquiries in these directions, which will be of particular interest to the psychologist. If these generalizations are true, if it can be proved even in the one case alone, of musical harmonies, that what sounds well to the ear, and therefore commends itself to the mind as agreeable, is that which

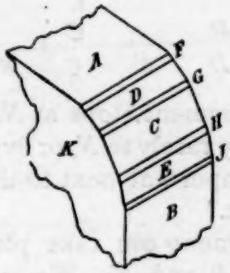


Fig. 1.

corresponds to harmonious development in the objective realities of crystal forms, then we have a purely objective explanation of our subjective discriminations. What sounds agreeable to our minds is that which has its real harmonious counterpart in objective nature, and thus the final source of mental satisfaction is that one finds his mental processes in accord with the great harmonies of Nature.

THE LAW OF INTER-RELATION IN CRYSTALLOGRAPHY.

Among the planes occurring on one crystal, and which may be great in number, certain planes are particularly important because of frequency of occurrence and size, others occur seldom, while others are quite rare. The rarer the plane, in general, the smaller it is, and the less certain is its identification. The feebler planes are arranged in series

between the principal or primary planes, in zones, with parallel intersections.

Let *A* and *B* (*Fig. 1*) be two primary faces (*K* may be a third). Then, by differentiation there is first formed between them the plane *C*, truncating with parallel edges the edge between *A* and *B*. If the differentiation proceeds further, we may have *D* and *E* truncating the edges between *A C* and *C B* respectively. The planes *D* and *E* are subordinate to *C*. By still further differentiation there are formed the still feebler truncating planes *F*, *G*, *H*, *I*. We thus have, so far, three stages of differentiation or development in the history of this zone.

$N_0 = A$								B
$N_1 = A$				C				B
$N_2 = A$		D		C		E		B
$N_3 = A$	F	D	G	C	H	E	I	B

Usually the development stops at N_1, often it goes to N_2, seldom to N_3, and very rarely to N_4 or over. The first derived plane, *C*, the most important next to the primary planes, is called the "dominant."

A similar development can take place on the edge between *A* and *K* or *B* and *K*. We would call these the "primary zones" *A B*, *A K*, *B K*, between the primary planes or nodes *A*, *B*, *K*. Further differentiation between one of the primary planes, as *K*, and the "dominant" of the other two, as *C* between *A* and *B*, gives us "secondary zones," such as *C K*, each with a "secondary dominant." Differentiation between two "prime dominants" would give tertiary zones, with "tertiary dominants;" while differentiation between a prime dominant and a secondary dominant would yield "quaternary zones" with "quaternary dominants." Zones, therefore, have their orders, though very seldom is the order above secondary. This scheme of development gives a rich mass of zones, especially if the primary faces are well developed and the differentiation between them goes up to N_2 or N_3.

In every zone, on every crystal, the arrangement of the planes relative to each other and to the primary planes of

that zone follows a determined law of numbers. If, by a simple geometrical device, the primary planes be represented in position by 0 and ∞ respectively, the dominant will be represented by 1, and the subordinate planes by ½ and 2, ⅓ and 3, ⅔ and ³/₂, etc., forming as a whole a harmonic progression such as 0 ⅓ ½ ⅔ 1 ³/₂ 2 3 ∞. These we may call harmonic numbers or the harmonic series. We will proceed to show how it applies to crystal planes in a zone.

Assuming that the physical particles which build up the crystal have primary forces of determined direction and intensity, and that these are the constructive forces which attract other particles and build up the crystal planes, we may further assume that the plane-building forces are perpendicular to the faces formed. The primary crystal-build-

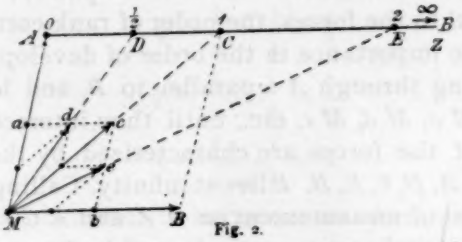


Fig. 2.

ing forces are therefore perpendicular to the primary crystal planes, and the secondary or derived forces are perpendicular to the secondary or derived planes. Considering, therefore, each plane of a crystal to be built by a force at right-angles to that plane, we may replace all the planes by their normals, and discuss these normals as representing the plane-building forces.

Taking the planes already illustrated in *Fig. 1*, we may, from any point inside the crystal, drop perpendiculars to the respective faces. Let *M* (*Fig. 2*) be the point chosen; then the primary planes *A* and *B* of *Fig. 1* are here replaced or represented by their normals *A* and *B*, the intermediate plane *C* by its normal *c*, *D* and *E* by their normals *d* and *e*, etc. The replacing of planes by their normals is a common device in mathematical crystallography. The primary forces *A* and *B* have therefore a determinate direction, the angle between

them being the same as the angle between the planes themselves, and the relative intensities of these forces are as the reciprocals of the axial ratios in the respective directions. Given, then, these primary forces of given direction and intensity, the "law of inter-relation" considers the differentiation or development of subordinate planes to have proceeded in the following manner:

The forces A and B split into two halves; one of each of these halves, a and b, unite to form the resultant c. The plane C results normal to c. The process repeating itself, $\frac{1}{2}\ a$ unites with $\frac{1}{2}\ c$ to a resultant d, and likewise $\frac{1}{2}\ b$ and $\frac{1}{2}\ c$ to e. By further repetitions of the same process still further, feebler resultants form between $a\ d$, $d\ c$, $e\ b$, etc. So we find the directions of the derived forces, and thence the position and order of rank of the derived planes. The planes stand normal to the forces, the order of rank corresponds to their relative importance in the order of development.

By drawing through A a parallel to B, and lengthening the forces $M\ a$, $M\ d$, $M\ c$, etc., until they intersect $A\ Z$, the directions of the forces are characterized by the points of intersection A, D, C, E, B. B lies at infinity. Calling $A = 0$, the starting point of measurement on $A\ Z$, and $A\ C = 1$, because it represents equal components of a and b; then will $A\ D = \frac{1}{2}$, $A\ C = 1$, $A\ E = 2$ and $A\ B = \infty$. The intersections on $A\ Z$ may be called the projection points of the different planes in the zone $A\ B$; the projection points characterize the position of the planes; their place is designated by the distances from A, by the numbers $0, \frac{1}{2}, 1, 2, \infty$. These numbers are the harmonic numbers, their series the harmonic series, and, if complete, the normal series. The law of development is expressed in the normal series and the harmonic numbers as follows:

Primary planes:	A				B
$N_0 =$ Normal series $0 = 0$					∞
1. Complication:	A		C		B
$N_1 =$ Normal series $1 = 0$			1		∞
2. Complication:	A	D	C	E	B
$N_2 =$ Normal series $2 = 0$		$\frac{1}{2}$	1	2	∞

3. Complication: A F D G C H E I B

N_3 = Normal series $3 = 0 \quad \frac{1}{3} \quad \frac{1}{2} \quad \frac{2}{3} \quad 1 \quad \frac{3}{2} \quad 2 \quad 3 \quad \infty$

It is clear how the higher series would look, but nature very seldom develops planes above the series N_3.

To investigate any series of numbers, so as to test them as to harmonic relations, it is necessary to make a transformation, to substitute for the end members 0 and ∞, and for the intermediate members their corresponding values. These intermediate values are easily found by dividing the distance of the number from one end by its distance from the other. Thus, given the series of members,

$$1 \quad \frac{4}{3} \quad \frac{3}{2} \quad \frac{5}{3} \quad 2$$

if we call the extremes 1 and 2, 0 and ∞ respectively, the intermediate members become—

$$\frac{4}{3} = \frac{\frac{4}{3} - 1}{2 - \frac{4}{3}} = \frac{1}{2}$$

$$\frac{3}{2} = \frac{\frac{3}{2} - 1}{2 - \frac{3}{2}} = 1$$

$$\frac{5}{3} = \frac{\frac{5}{3} - 1}{2 - \frac{5}{3}} = 2$$

and the series becomes in harmonic numbers—

$$0 \quad \frac{1}{2} \quad 1 \quad 2 \quad \infty = N_2$$

Or, in general, calling Z and Z_2 the two extremes of any series of numbers, Z any intermediate number, and p the corresponding harmonic number of a harmonic series, then—

$$p = \frac{Z - Z_1}{Z_2 - Z} \text{ for } Z_1 = 0 \text{ and } Z_2 = \infty$$

The study of crystal forms, particularly by the method of gnomonic projection, in which all zones are projected in straight lines, and the position of planes in series can be directly measured or calculated, has substantiated the "law of inter-relation" as being the law governing the distribution of planes in zones. We will now study the diatonic scale in the light of the same law, transforming its members into harmonic series, and therein making clear the fundamental relations of the various notes to each other.

[*To be concluded.*]

Notes and Comments.

TESTS OF NERNST LAMPS FOR PUBLIC LIGHTING.

At a recent meeting of the British Institution of Electrical Engineers in London the results of the experiments with the Nernst electric light for public lighting purposes were given. A mile of a street in Hackney, one of the London suburbs, has been lighted by means of these lamps to obtain conclusive data regarding their durability, efficiency and suitability for such work. The main difficulty experienced was in connection with the starting of the light. This, however, was overcome by means of the automatic heater, which is put out of action directly the lamp lights up. But the result of this attachment was not attended with absolute success, since considerable uncertainty exists in connection with the durability of the glower. Some glowers lasted only 15 hours, while others remained efficient for 1,070 hours, but the average life was 305 hours. This lack of uniformity constitutes one of the greatest objections to the wider utilization of the Nernst lamp for public lighting, despite its superiority in many important features, and will necessitate considerable improvement before it is extensively adopted for illumining the streets, with that economy which is essential for such purposes.

STRANGE FACTS ABOUT THE EUCALYPTUS.

Mr. D. E. Hutchins, of Cape Colony, who in 1882, in conjunction with Sir A. Brandis, discovered the remarkable sun-power storage capacity of the eucalyptus, has again been drawing attention in *Nature* to this extraoadinary feature of the tree. According to Mr. Hutchins, a eucalypt plantation in tropical mountains, such as in South Africa, under favorable circumstances, stores up about one per cent. of the solar energy received on the unit of area and it is considered much cheaper in some parts of Cape Colony to plow up the land and plant a forest of quick-growing trees than to import coal.

In 1882 Mr. Hutchins and Sir A. Brandis, as the result of their experiments, discovered that eucalypts planted on tropical mountains produce fuel at the rate of 20 tons—dry weight at 60 pounds per cubic foot—per acre per year in perpetuity. The eucalypt plantation reproduces itself when cut without further expense, and its dry timber, heavier than coal, has an equal or a higher thermal power, bulk for bulk, than coal. This result was obtained as a measurement of the maximum yield of *Eucalyptus globulus* on the Nilgiris, Southern India. If a chance tree on a chance mountain in a chance soil can produce the equivalent of 20 tons of coal per acre per year, it seems not unreasonable to suppose, Mr. Hutchins suggests, that by selection double this, or 40 tons, can be produced. A powerful sun, a heavy rainfall, and a very rapid forced growth are the essentials of such a production of wood fuel. A glance over the rainfall map of the world shows these conditions are fulfilled over about 8,000,000,000 acres of its surface, which is between one-fourth and one-fifth of the total land surface of 35,200,000,000 acres. One-half of this area under forest might thus yield the equivalent of 160,000,000,000 tons of

coal yearly, which is more than 288 times the world's present consumption of coal, assuming that coal and eucalypt timber are of approximately equal heating power. On the basis of the actual forest yield of the present day, we have half of this, or the equivalent of 80,500,000,000 tons. In Germany, one fourth of the total area is under forest, and taking the German standard of one-fourth forest, on the basis of the present maximum yield we should obtain 40,250,000,000 tons; while if the maximum forest yield be converted to an average forest yield there would still remain a yearly product of 20,175,000,000 tons, which is rather more than thirty times the world's present consumption of coal. Thus it is seen that the yield of firewood from the world's tropical and extra-tropical forests, wherever they are fully stocked and scientifically worked, will yield the equivalent of from 30 to 122 times the present consumption of coal, or even up to 243 times the present consumption, if by cultivation the present timber yield be doubled, as it might be without difficulty.

THE ANCIENT RUINS OF RHODESIA.

The remarkable ruins in South Africa, which by many are boldly declared to be the remains of King Solomon's mines, are fully described and illustrated in a recent work by R. N. Hall and W. G. Neal. No theories are offered for the presence of the ruins in savage lands. The authors, however, seem to incline to the opinion of Prof. Keane, which is, in brief, that "the 'gold of Ophir' came from Havilah (Rhodesia), and was worked and brought thence first by the Himyarites (Sabæans and Minæans), later by the Phœnicians. . . . The numerous objects of Semitic worship and the fragments of Himyaritic script found at Zimbaye and elsewhere south of the Zambesi leave no reasonable doubt that the old gold-workings and associated monuments of this region are to be ascribed to the ancient Sabæans of South Arabia and their Phœnician successors."—*Scientific American Supplement.*

THE USE OF PHOSPHORUS MATCHES PROHIBITED IN GERMANY.

The Reichstag has passed a bill forbidding the use of white or yellow phosphorus in match-making after January 1, 1903. The Secretary of the Interior, speaking in favor of the bill, said that phosphorus not only caused necrosis three or four years after a workman had left a match factory, but that the disease thus contracted was hereditary, so that whole families were affected. So subtle were the effects that the bones were fractured without the person at first being even aware of the fracture. The Government has reported favorably upon a match-manufacturing process said to be safe and harmless.—*Scientific American.*

ALCOHOL AS FUEL FOR INTERNAL COMBUSTION ENGINES.

Tests made by C. W. Weiss, at the Mietz & Weiss Engine Works, New York City, with Cuban and Brazilian cheap alcohol as fuel in their standard kerosene engine, have been reported as entirely satisfactory. The object was to substitute alcohol for kerosene, the former being considerably cheaper and

more readily obtainable in Cuba and South America, where many of these engines are shipped. It was found that a mixture of 4 pints alcohol and 2 pints water developed 4 horse-power for one hour. The mixture of alcohol varies, however, with the quality of the former being limited by the practical degree of compression prior to combustion. The specific gravity of the mixture is 0·9; that of the pure alcohol was 0·794. The development of the alcohol engine is of the greatest importance to the power question of Cuba, Brazil and the Philippine Islands.

A NEW POWER PLANT AT NIAGARA FALLS.

It is stated on good authority that the Lackawanna Steel Company will use power from Niagara Falls to operate the immense amount of machinery at their new plant at Stony Point, Buffalo. Arrangements have not been entirely completed, but the directors have contemplated this step for some time, and plans have been drawn for part of the work. It is the intention of the company to install their own generators at the Falls by special arrangement with one of the existing power companies or by the purchase outright of one of the smaller power companies, and to connect same with their steel plant by their own special line of wires.

INGENIOUS DANGER SIGNALS.

Some of the devices invented for use upon railways are exceedingly practicable as danger signals, but why they are not generally adopted is one of the things that are not easily understood. One of them is a torch which is attached to a pointed rod easily driven into a tie to keep it upright. By unscrewing a friction cap on the torch itself a bright red light, which neither rain nor wind can extinguish, burns for fifteen minutes, and is visible for one mile, making it unnecessary to send a brakeman back with a red flag.—*Iron Age.*

PRODUCTION OF MAGNESITE IN 1902.

The report on the production of magnesite in 1902, by Dr. Joseph Struthers, will soon be issued by the United States Geological Survey.

The production for 1902 was 3,466 short tons, valued at $21,362, as compared with 13,172 short tons, valued at $43,057, in 1901. The imports of crude and calcined magnesite during 1902—chiefly from Greece and Austria—amounted to 49,786 short tons ($373,928), as compared with 33,461 short tons in 1901.

In the crude state magnesite is used in the manufacture of carbon-dioxide gas, by treatment with sulphuric acid or by the application of heat alone. In the former case magnesium sulphate is obtained as a by-product, which yields Epsom salts, the production in 1902 being estimated at about 50 000 barrels. The chief use of the carbon-dioxide gas derived from magnesite is to charge or carbonate mineral waters. In its calcined state the consumption of magnesite has increased very largely since 1899, owing to its use as a refractory lining for furnaces and kilns. As a commercial product the mining of magnesite is practically confined to California, and principally to Tulare County.

Book Notices.

Annuaire pour l'an 1903, publié par le Bureau des Longitudes: avec des notices scientifiques. In—16 de près de 850 pages avec figures. Paris: Gauthier-Villars (1 fr. 50; franco, 1 fr. 85).

The house of Gauthier-Villars issues as usual the *Annuaire des Bureau des Longitudes* for the year 1903.

This compact little volume contains the customary collection of astronomical and physical data which makes it so indispensable to the engineer and the man of science. Appended thereto are some interesting scientific notes, among which may be mentioned communications by M. R. Radase, on Shooting Stars and Comets; by M. J. Janssen, on Science and Poesy; and finally, the discourses pronounced at the obsequies of MM. Fayl and Cornu. W.

Analysis, Detection and Commercial Value of the Rare Metals. By J. Ohly, Ph.D. 8vo, pp. 216. Denver, Colo.: Industrial Printing and Publishing Company. 1903.

The recent advances in the field of illumination and the manufacture of special steels has brought the rarer metals, such as tungsten, vanadium, molybdenum, titanium, thorium, cerium and its allies, the rarer platinum metals and others, into prominence, and a handbook giving the most reliable analytical methods for their detection and estimation should prove very useful to chemists and others who are called upon to identify these substances. The author has endeavored to cover this ground. W.

The Bonus System for Engineering Works. The Cassier Magazine Company, 3 West Twenty-ninth Street, New York. (Price, 10 cents.)

The publishers of the *Cassier's Magazine* have just issued in pamphlet form the article on the Bonus System which appeared in their Machine Shop number, published a few weeks ago. Of the various methods of encouraging increased production among workmen, especially in engineering works, no system has ever produced such satisfactory results as some form of a bonus system, but a bonus system without some method of imparting the necessary information both to the employer and the employee is not likely to prove workable. This pamphlet deals not only with the system, but with the method of accomplishing what the system aims to accomplish—increased production and satisfied workmen.

Experiments with Vacuum Tubes. By Sir David L. Salomons, Bart., M.A. (With 54 illustrations.) 12mo, pp. vii + 79. London and New York: Whittaker & Co. (Price, 2 shillings.)

The author presents in this booklet some new methods which he has devised for the study of the phenomena caused by the electric discharge in so-called vacuum tubes. He has observed that many of those phenomena are

obscured or confused, and their correct interpretation rendered difficult if not impossible by reason of the employment of currents of very high E.M.F. and large currents. He accordingly employed in his study of the phenomena very small E.M.F. and very small current. By this method, he claims, the difficulties which beset earlier investigators disappear and the phenomena are seen in their purity. Then on raising the E.M.F. successive superadded phenomena appear, which would have been extremely puzzling had the start not been made in this manner. Then follows a detailed account of numerous experiments under varying conditions with a great variety of tubes.

A second part of the book describes the author's observations on the effects produced upon electric discharges in rarefied gases when placed in the magnetic field. W.

Report of the Commissioner of Education for the year 1900–1901. Washington: Government Print, 1902.

This publication, comprising nearly 1,300 pages octavo, exhibits very creditably the thoroughness with which this Bureau conducts its business of inquiring into the questions bearing on education in the United States.

In all there are nineteen chapters treating respectively of the following themes: Co-education of the sexes in the United States; Education in the Philippine Islands; foreign universities, etc.; education in Alaska; domestication of the reindeer in Alaska; Consular reports, city school systems; universities, colleges and technical schools; professional and allied schools; agricultural and mechanical colleges; normal schools; secondary schools; manual and industrial training; commercial and business schools; education of the colored race; reform schools; schools for the defective classes; instruction in mining engineering; current topics; miscellaneous educational topics. W.

Report on the Engineering Trades of South Africa. By Ben. H. Morgan, Special Commissioner, etc. (With numerous tables, appendices and reproductions of special plans, drawings and photographs.) 8vo, pp. xii + 192. London: P. S. King & Son (for the National Industrial Association), 1902.

The author was named by the English "South African Trade Committee" as special commissioner to visit South Africa, and, after personal inspection and inquiry on the ground, to report upon the condition of the engineering trades of that country, in the general interest of British manufacturers and merchants.

The work contains the results of the author's mission. American manufacturers especially will be interested in consulting it. W.

Outlines of Electrochemistry. By Henry C. Jones, Associate Professor of Physical Chemistry in the Johns Hopkins University. 8vo, pp. vi + 106. New York: D. Van Nostrand Company. (Price, $1.50.)

This volume, in a concise and lucid manner, presents the most recent theories of chemical action which have caused so radical a change in the views of chemists. None is better qualified than the author to present this subject in the most intelligible and interesting manner. W.